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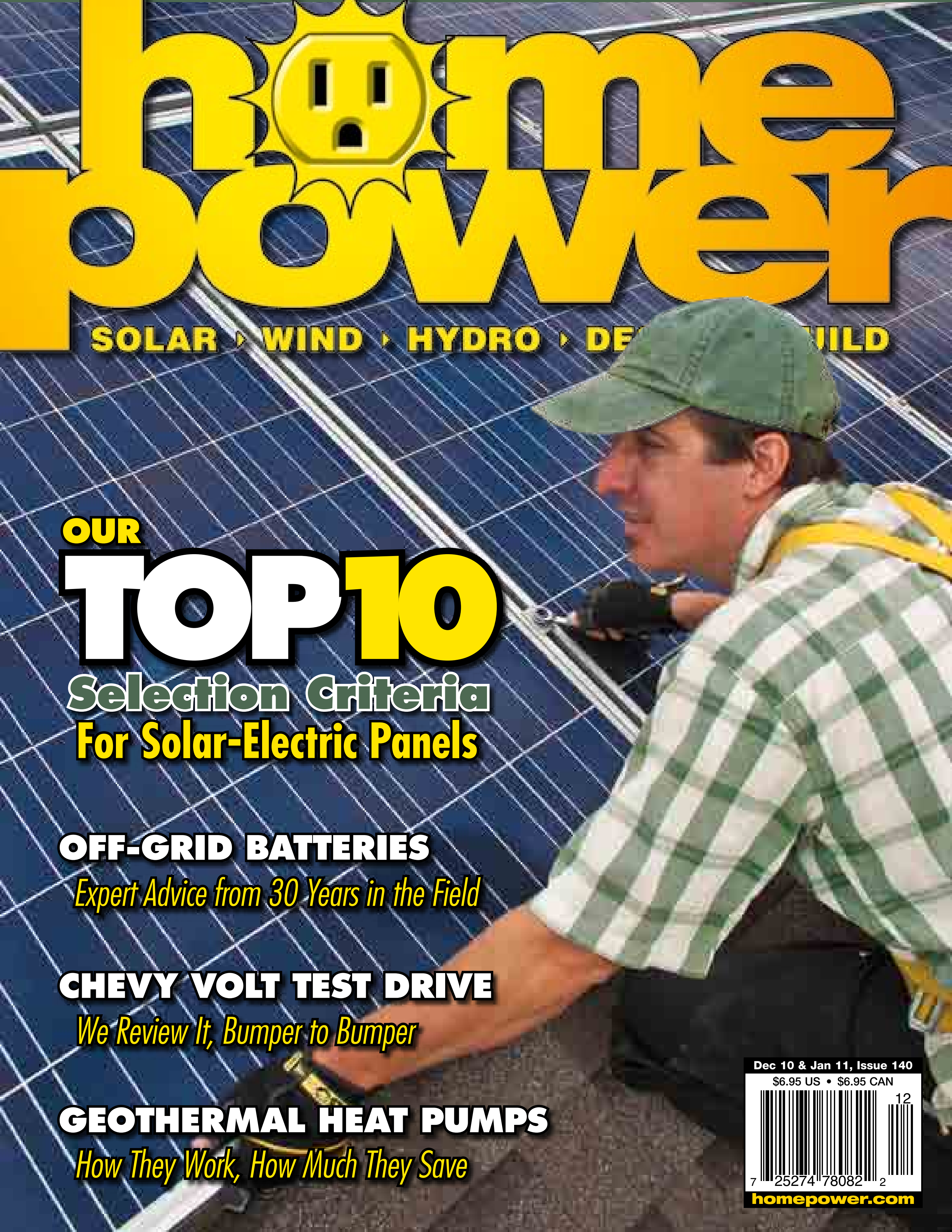

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What have you come to expect from your solar inverter company? At Fronius, we think you should expect a lot and strive to deliver that with innovative products and world-class customer service. We call this **the Fronius Difference**.

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Fronius works to provide responsive customer support, quality products, and proactive solutions when issues do arise.

Knowledgeable tech support
All calls reach our top-tier tech support on the first call, which is available 12-hours a day on weekdays.

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When you have a question, a prompt response can be critical. Fronius knows this and works very hard to return emails and phone calls in a timely fashion.

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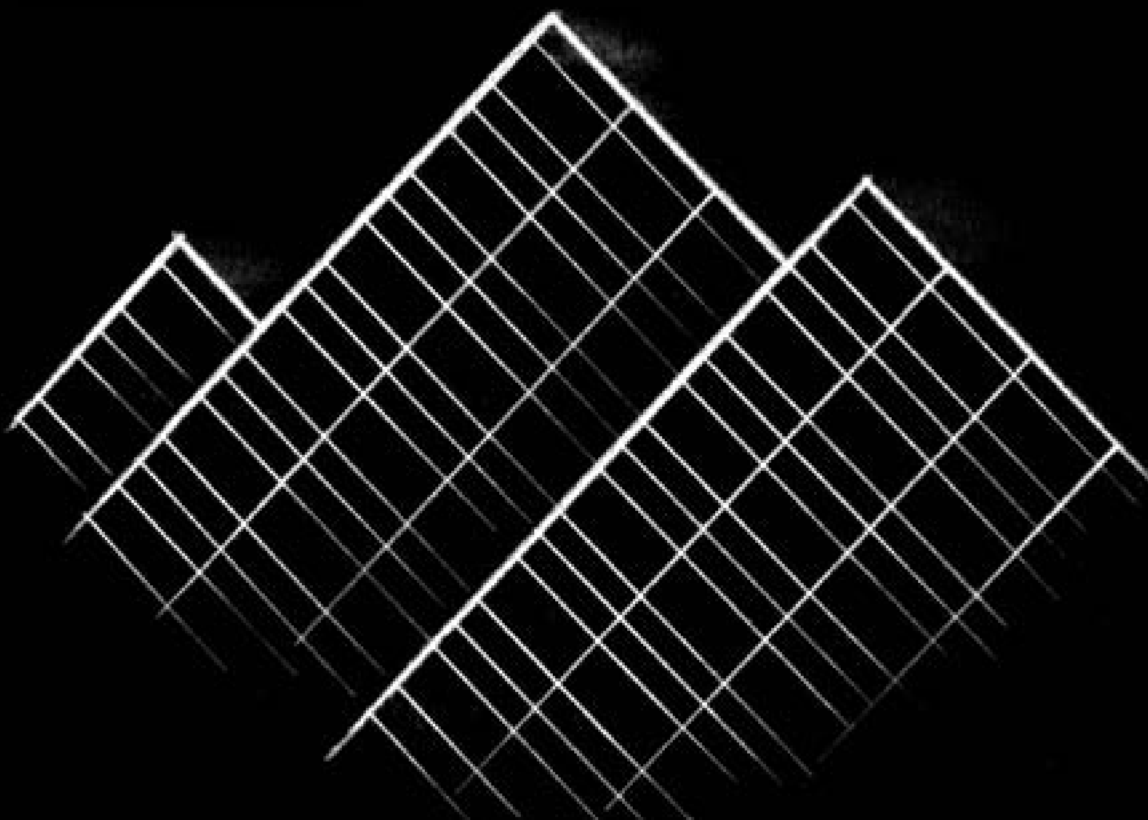
Our standard ten-year warranty provides comprehensive coverage in straightforward language and is tracked by the serial number, not the owner, making paperwork unnecessary. And customers have the option to purchase a five-year warranty extension to bring the total warranty life to 15 years.



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On the Web

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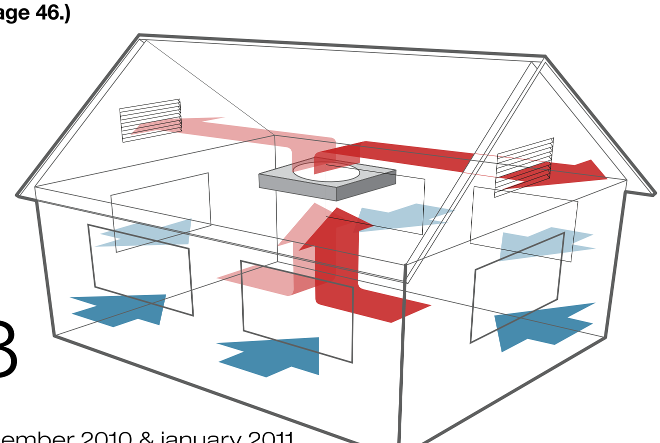
On the Cover

Oregon-based True South Solar integrator Eric Hansen installs REC 225-watt PV modules on an Ashland, Oregon, residence. (Find out how to select the best modules for your application by checking out our "PV Purchasing" article on page 46.)

Cover photo: Shawn Schreiner



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Top to bottom (this page): SunPower; Guy Marsden; AirScape; opposite page: Harry Martin; East Penn Manufacturing; ©iStockphoto.com/mfilippo

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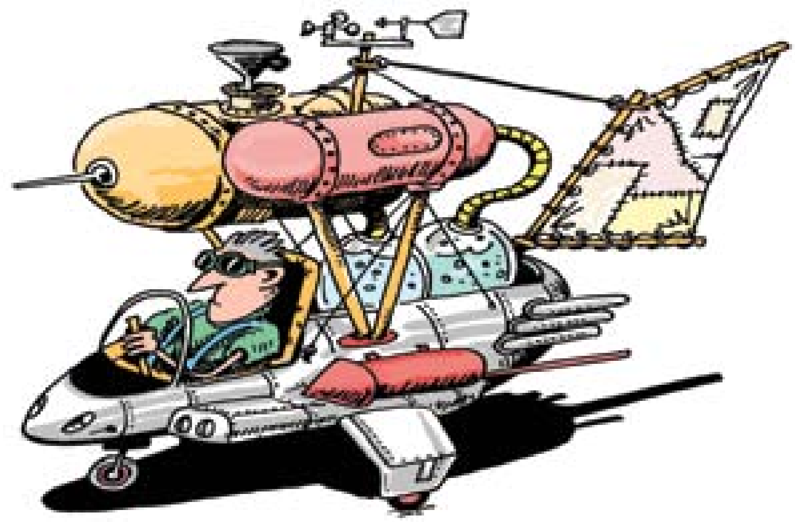

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In Back

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Third Time's a Charm?

Last October, Council on Environmental Quality chair Nancy Sutley and U.S. Energy Secretary Steven Chu announced plans for PV and solar hot water systems to be installed—again—on the White House residence.

Many folks know the story about the Carter administration having solar hot water modules installed on the White House in 1979, and then the Reagan administration removing them in 1986. But only a few are aware that, in 2003, the G.W. Bush administration had a 9 kW grid-tied PV system installed on a White House grounds maintenance building, along with two separate SHW systems. Why was this information not widely broadcast (though reported in *HP94*)? Any of those "reasons" why won't make much sense to those who live with renewable energy. Nevertheless, the systems have been in place for more than seven years, quietly making electricity and hot water.

Courtesy 350.org

Carter-era SHW collectors at Unity College in Maine.

So had the SHW collectors that were removed from the White House in 1986—on a rooftop at Maine's Unity College. But Unity students and author/climate activist Bill McKibben of 350.org had other grand ideas. They took down one of the old White House collectors from the college roof, and after a nationwide tour, brought it back to its original digs, hoping to convince the Obama administration to try it again. Unfortunately, the administration wanted little to do with it, and showed McKibben and the Unity students the door.

But 350.org is media-aware, and a press conference and subsequent negative publicity from the renewable energy community caused the administration to move forward on the project, which should have been a no-brainer in the first place. Less than a month after the student visit, on October 5, the Obama team bowed to the pressure and announced plans to put PV modules and SHW collectors on the White House.

As users and advocates of renewable energy, it is interesting to reflect on these past, present, and future White House solar installations (and de-installations). We're encouraged to see a large effort aimed at renewable energy and growing numbers of clean jobs. It is indeed timely for the Obamas to lead by example and produce their own "home power." Once the White House residents are enjoying the benefits of their new systems, perhaps they, like us, will be inflicted by the renewable energy bug—implementing creative strategies and technologies to reduce their energy consumption, and increasing renewable energy production to reduce their carbon footprints. And we envision a copy of *Home Power* magazine lying on the Obamas' coffee table*, there to help them every step of the way.

—Justine Sanchez and Michael Welch, for the *Home Power* crew

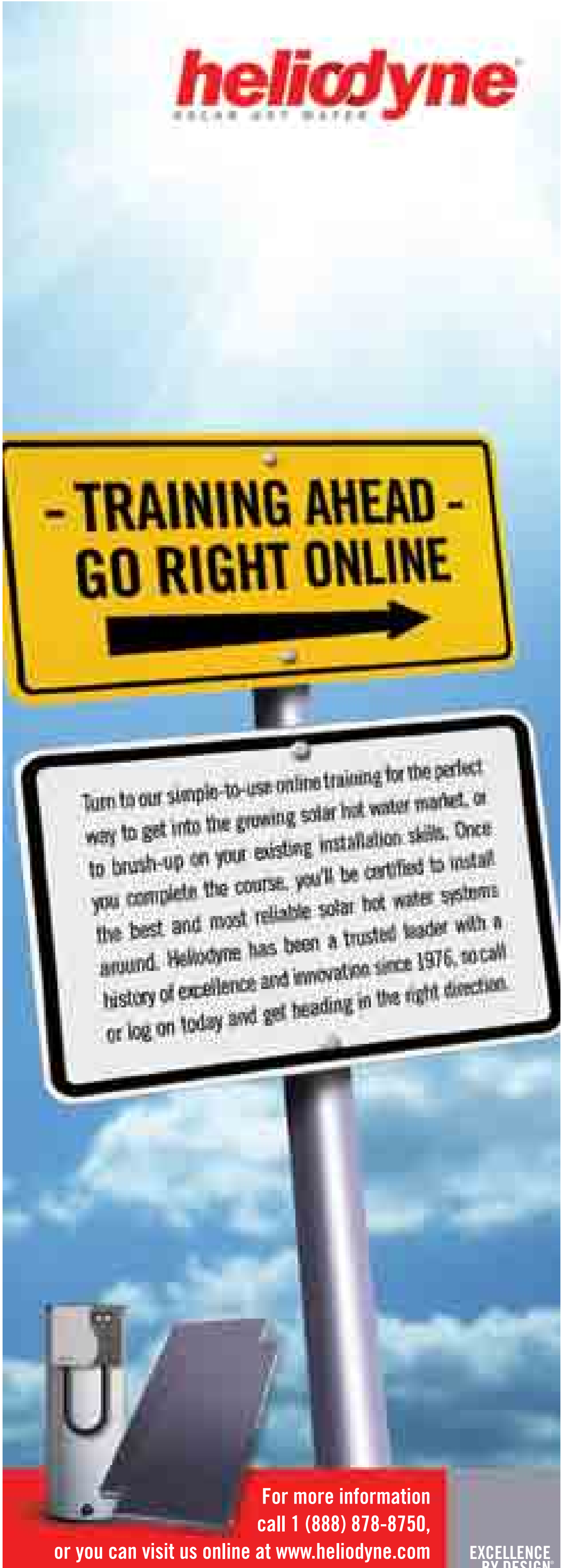
*Just to be sure, we sent a complimentary subscription to the White House.

Think About It...

The word "energy" incidentally equates with the Greek word for "challenge." I think there is much to learn in thinking of our federal energy problem in that light. Further, it is important for us to think of energy in terms of a gift of life.

—Thomas Carr

FLEXmax
OutBack



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Jobs Study: Solar Workforce on the Rise

With the economy suffering in recent years, the job outlook looks generally dim—but the solar industry could be a bright star in dark skies.

New research confirms what many in the industry have long sensed: The solar workforce is strong and growing despite the slow economy.

A national survey of solar labor market conditions authored by The Solar Foundation (TSF), a solar research and education nonprofit organization in Washington, D.C., shows that more than 50% of all solar firms expect to add jobs over the next year, while only 2.2% expect to make layoffs.

According to the study, solar firms—any company performing work related to PV, solar water heating (including pool heating), and solar space heating and cooling—expect to add jobs at a pace that is much faster than the general economy's growth. Solar companies anticipate their workforce to grow by 26% over the next year—a significantly higher rate than the economy-wide expectation of 2% growth. This increase represents 50,000 new jobs spread across the solar-related industries, with approximately 24,000 of these new hires spending at least 50% of their time on solar projects.

"With the national unemployment rate hovering around 10%, this is great news," says Andrea Luecke, acting executive director of TSF. "We know that the vast majority of Americans want to see more solar, but our findings prove that solar represents much more than a popular concept—it represents a stable and secure livelihood for thousands of families."

The study is the first industry-wide effort to quantify solar jobs across the entire industry, including manufacturing, installation, research and development, sales, financing, distribution, utility, and other solar-related businesses.

"As the solar market matures, the nature of the workforce is changing," Luecke says. "You no longer have to be an installer or an electrician. People can enter the solar workforce with varying levels of skill, education, and experience. There are jobs to be had in sales, customer service, consulting, planning, marketing, legal, and human resources."

The findings show that more than 16,000 firms in the United States derive at least some revenue from solar goods and services, and identify 93,000 solar workers—those who spend 50% or more of their time on solar-related projects.

The study could have broad implications for the industry, providing at long last an accurate measure of the market for news stories, legislative initiatives, and funding proposals.

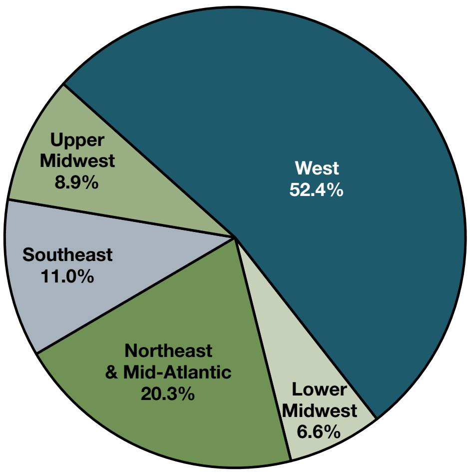
Misperceptions about the size and nature of the solar industry are common and potentially damaging to America's solar prowess, according to Thomas P. Kimbis, director of policy and research for the SEIA and chairman of TSF.

"We are continually characterized as being smaller and much more localized than we actually are," he says. "There's a misperception that solar only exists in Florida

Topher Donahue

Jobs in the solar industry fall into many skill sets.

Solar Employers by Region



Courtesy Suntech

or in the Southwest. This study shows that solar is being installed across all 50 states and that there are jobs being created across the industry because of the growing demand for renewables."

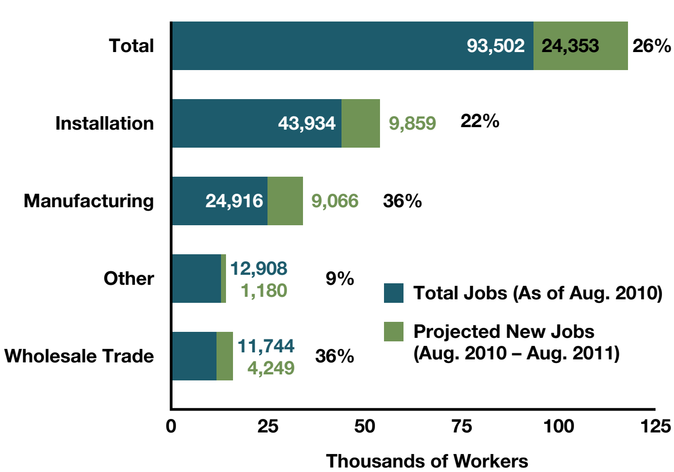
The online and telephone surveys, carried out in July and August 2010, collected responses from nearly 2,500 solar companies across the country. In addition to polling known solar firms registered with industry, and trade and government groups, the study questioned a random sampling of companies within various construction, wholesale trade, and manufacturing industries that have solar-related portions in their businesses.

"This survey fills in the holes of other studies," says Phil Jordan, president of Green LMI, a consulting firm in Boston that conducted the data analysis for TSF. "Unlike other studies that only reach out to the known universe of solar companies, this study accounts for the unknown universe of companies that conduct solar-related business but are often overlooked. Because it is a better representation of the entire industry, we can draw broader conclusions with a higher degree of confidence."

TSF also assessed the job growth by key subsectors. Manufacturing, a segment traditionally thought to be one of the weakest links in the domestic solar market, is expected to grow by 36% this year, adding roughly 9,000 new jobs that primarily focus on solar projects.

Wholesale trade rivals manufacturing as one of the fastest-growing subsectors, with 36% growth—equaling 4,249 new jobs. Of those, the greatest demand will be for production workers and salespeople. The installation subsector is projected to gain 9,859 new jobs, representing 22% growth.

The Current Solar Workforce



Fastest Growth

According to The Solar Foundation's research, five occupations are expected to grow the fastest over the next year:

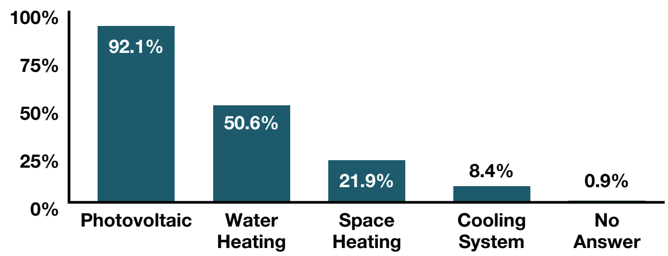
- Photovoltaic system installers (51%–66% growth)
- Electricians with specific experience in solar installations (42%–55% growth)
- Sales occupations at wholesale trade firms (40%–49% growth)
- Sales representatives or estimators at installation firms (39%–47% growth)
- Roofers with specific experience in solar installations (36%–49% growth)

Based on survey responses and data collected by Idaho-based Economic Modeling Specialists, the Southeast is expected to add the most jobs across all solar subsectors over the next year, followed by the Northeast and Upper Midwest.

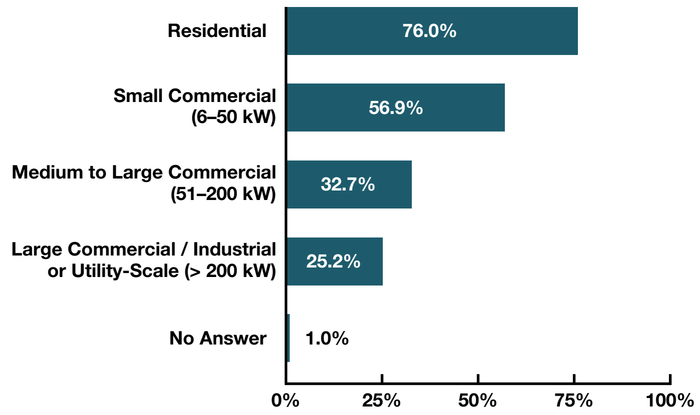
TSF's study was made public in October 2010 at Solar Power International in Los Angeles. TSF plans to update the survey periodically, as funding allows. On the next round, TSF plans to "dig deeper" and gather information pertaining to wages, benefits, and education levels. TSF is also working with the U.S. Bureau of Labor Statistics to define solar job categories that can be included in future census reports.

—Kelly Davidson

Firms by Technology / Installation



Types of Systems Installed



Solar Industry Growth = Job Growth?

Many economists and industry insiders are forecasting steady growth in the solar market over the next couple of years, but the question remains: Will the increased demand translate to new jobs?

Shayle Kann, an energy analyst with Boston-area GTM Research, estimates that demand for PV system installations will grow from $5.6 billion in 2010 to $9.6 billion in 2015—from 866 MW to 4,470 MW.

"The U.S. solar market is still in its very early stages, but it has enormous potential. We expect the PV sector to roughly double this year and continue growing steadily for years to come. Such substantial growth will bring new jobs. That was the case in Germany and several leading solar markets," Kann says.

In particular, Kann predicted significant growth in domestic manufacturing jobs in the coming years. According to his firm's projections, the United States will have 3.9 gigawatts of PV module manufacturing capacity by 2012, up from 875 megawatts in 2009.

But not everyone is as optimistic about solar-job growth. According to John A. Laitner, director of economic and social analysis for the American Council for an Energy Efficient Economy, employment in the solar market will remain "relatively flat" for the near term.

"There is quite a bit of uncertainty right now. With the economy limping along, many firms will choose to meet

New Projects in the Solar Economy

The findings of The Solar Foundation's study underscore the importance of domestic manufacturing in growing the solar workforce. Here's a glimpse of a few projects fueling the solar economy.

- China-based Suntech Power Holdings Co. opened a manufacturing plant in Goodyear, Arizona, in October. The plant will employ about 75 people and produce 30 megawatts (MW) of crystalline silicon photovoltaic modules per year.
- San Jose, California-based PV module company Solexant plans to open Oregon's first thin-film solar manufacturing facility in the Portland suburb of Gresham. The 100 MW capacity plant will employ as many as 200 people.
- Confluence Solar plans to build a $200 million manu–facturing, warehousing, and distribution facility in Clinton, Tennessee. The plant, which will produce monocrystalline silicon ingot for use in PV products, is projected to create 250 jobs.

increased demand by putting their existing employees to work harder rather than hiring additional people," Laitner says.

The most marketable people in today's solar market, Laitner says, are those who have hands-on technical skills and can articulate the ins and outs of the technology.

"We need more quality workers on the front lines to install systems, hold people's hands, and walk them through the technology," Laitner explains. "The industry's growth is viral. There is a tremendous demand for people who can communicate the advantages of solar and make consumers feel confident about the technology."

According to Kann, sustained growth in the U.S. solar workforce will depend largely on whether state governments continue to drive solar demand with policies and incentives, such as the adoption of aggressive renewable energy portfolio standards for utilities.

On a national scale, the most immediate threat to the solar labor market stems from the expiration of the Clean Energy Treasury Grant Program at the end of this year, Kann says.

The program, which was created as part of the American Recovery and Reinvestment Act of 2009, provides cash grants in lieu of tax credits for renewable energy projects. It has helped to bring 4,250 megawatts of renewable energy online and generated more than 143,000 green jobs, according to the Lawrence Berkeley National Laboratory.

"The program enabled continued growth in the market despite difficult financial times," Kann says. Not renewing that program "could take us back to a place where financing becomes a bottleneck for solar projects and derails any significant growth in the workforce."

—Kelly Davidson

Seeking a Solar Job?

Check out these online job boards to find your place in the sun.

Green Jobs • www.greenjobs.com

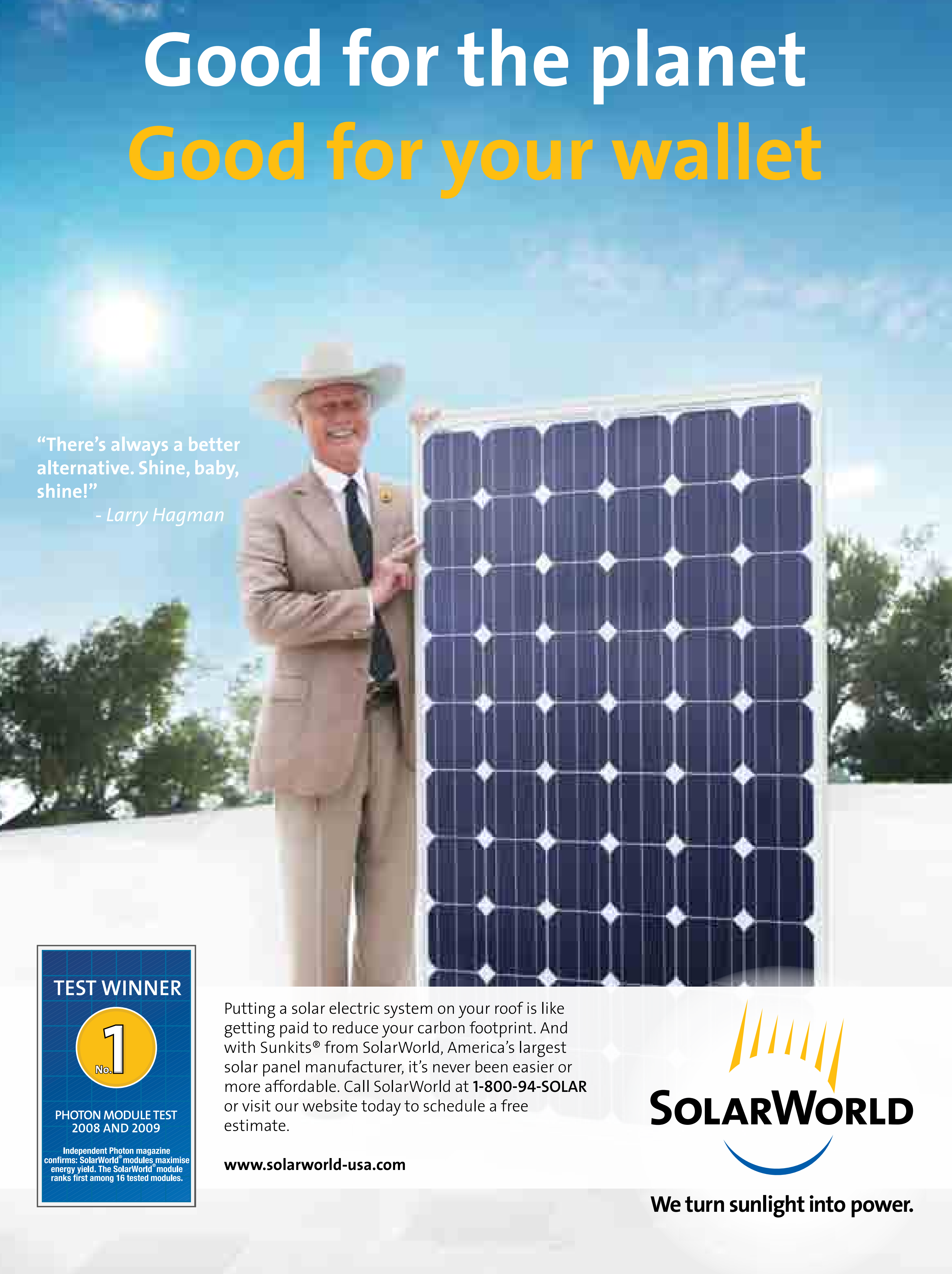
***Home Power* magazine** • www.homepower.com

Jobs in Solar Power • www.jobsinsolarpower.com

Renewable Energy World • www.renewableenergyworld.com

Solar Energy Industries Association • www.jobtarget.com/home/index.cfm?site_id=4204

***SolarPro* magazine** • www.solarprofessional.com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Courtesy Black & Decker

Black & Decker's
TLD100 Thermal Leak Detector

Black & Decker's **TLD100 Thermal Leak Detector** ($80 MSRP, www.blackanddecker.com, $50 street price) is an infrared thermometer used to scan surfaces in a home and identify areas where thermal leaks are occurring. You set the threshold temperature to 1°F, 5°F, or 10°F, depending upon the sensitivity you wish it to indicate. Then you aim at a reference target, which shines a green LED light on the spot when the reference temperature is determined. Next, the TLD is aimed at the surface you wish to check. The LED beam changes to blue for cooler spots or red for hotter spots, and a digital display on the unit shows a numerical reading of the surface temperature.

While the accuracy of the temperature reading is marginal (at best ±2.5°F at 73°F), its resolution of 0.1°F can easily find temperature differentials to search for thermal performance problems with walls, windows, floors, and doors. Other creative applications are possible—for example, using it to find suspected damaged cells in a PV array, which should be hotter than the fully functional cells.

—Justine Sanchez

Bryce Fastener's Penta Nut

High-Security Mounting Hardware

Courtesy Bryce Fastener

Bryce Fastener's new **Penta Nut** high-security mounting hardware (www.brycefastener.com) helps thwart would-be PV module pinchers. PV modules are expensive and increasingly attractive targets for thieves. The Penta Nut is one way to make removing modules from their mounts more difficult by requiring a specialized socket for removal. They cannot be removed with a vise grip or other security bits. These stainless steel nuts can be used in place of standard hardware, and using one on the end of a special threaded stud can make a bolt to secure both ends of the attachment.

—Justine Sanchez

Courtesy Caleffi

Caleffi's iSolar BX
Differential Controller

Caleffi's **iSolar BX** (www.caleffi.us) is a multifunctional temperature differential controller with add-on functions. It can be used for a wide variety of solar thermal heating applications. It is equipped with four relay outputs, as well as two PWM outputs for energy-saving high-efficiency DC pumps. The controller has five Pt1000 sensor inputs, two analog Grundfos sensor inputs, and one impulse flow meter input. Twenty-six predefined settings arrangements can control standard solar water heating systems, supplemental space heating, multiple storage tanks, heat dumps, and storage tank boost heating. This controller features a large LCD display and six function keys. The easy-to-use icons assist in operating and customizing a solar heating system's function. The integrated SD memory card slot enables easy data logging with quick and effortless transfer of logged system data to a PC.

—Chuck Marken

Energy-Smart Apps

Courtesy Solmetric

Energy Savings Calculator

Developer: Bruce Wayne
Compatibility: Android
Cost: Free

Calculate how much money you will save per week, month, and year when you make energy-efficiency upgrades to your home. Enter the power use of your old appliance and what the new appliance will use, and calculate the savings.

Solmetric iPV

Developer: Solmetric
Compatibility: iPhone, iPad Touch
Cost: $29.99

Perform a solar site analysis quickly. This app utilizes the compass and inclinometer functions of the iPhone, along with its own built-in GPS and sun-positioning algorithms, to determine when your solar array will be in direct sun and when it will be shaded by the local obstructions. It can also predict your site's monthly, seasonal, and annual solar potential, as well as generate a monthly and annual kWh production estimate based the model of PV modules and inverter your system uses.

MeterRead

Developer: Zerogate
Compatibility: iPhone, iPod Touch
Cost: $2.99

Keep tabs of your electric meter on the go. Start by entering your current meter reading. MeterRead will monitor the total kilowatt-hours used since the last read, and predict your total energy usage for the next 30 days. Challenge yourself to do better—monitor how changes in usage behavior (i.e. turning off lights and changing your thermostat) affect your consumption, and measure the effect of energy-efficiency upgrades, like new appliances, windows, and insulation.

Power Stoplight Mobile

Developer: Smart Power Devices
Compatibility: Android, iPhone, iPod Touch, iPad
Cost: $0.99

Help ease the strain on potentially overloaded electrical grids. Follow the stoplight to know the best time to run major electrical loads based on supply and demand levels for your region. This new app monitors utilities' time-of-use rate programs for more than 25 regions throughout the United States to help you take advantage of dynamic pricing. For those with renewable energy systems, a blue light indicates optimal times for net metering.

Home Energy Performance

Developer: Qreative Medias
Compatibility: iPhone, iPad
Cost: $4.99

See how your home measures up. This newly launched app allows you to either rate your own property or check out the energy profile of a home you might be thinking about buying. The U.S. version of this European-developed software is based upon recommendations of the U.S. Environmental Protection Agency's Energy Star program and the U.S. Department of Energy's Building America Program.

—Kelly Davidson

on the web

Open iTunes to buy and download apps for Apple devices. For Android apps, browse the Android Market.

Working Bikes Cooperative

Bringing Pedal Power to the World

Bicycles are among the most efficient transportation options available. But in North America, they are often relegated to recreational status, with even functional or repairable bicycles discarded for the latest and greatest models.

In the "developing world," where people primarily travel by foot and carry loads on their backs, bikes are a huge step forward, offering a quicker way to get around and an easier method of hauling cargo. Because of the difference in standard of living, a bike that may be "worth" $20 in the United States could be worth much more to an individual in a developing country.

The Chicago-based Working Bikes Cooperative (WBC) is bridging these two worlds by recycling discarded bikes and distributing them in poor countries around the world. Eight to 10 times a year, WBC ships containers of refurbished bicycles to countries such as Ghana, Nicaragua, El Salvador, Angola, Cuba, and Uganda. The organization also donates bikes to people in poor areas of North America, such as the Gulf Coast after the recent hurricanes, and to immigrants and refugees newly arrived in Chicago.

Courtesy Working Bikes Cooperative (4)

Bicycle recipients in Angola.

web extra

Organize a bike drive in your community. Visit **www.workingbikes.org/bikedrive** for tips and hints on setting up an event in your region.

Above: A custom-built, hand-pedaled trike in Guatemala.

Right: Bikes in varying stages of repair in a WBC warehouse in Chicago.

The nonprofit WBC starts by soliciting donations of used bicycles from across the Midwest. As a result of "bike drives," where folks can drop off their used bicycles, the organization gathers more than 5,000 bicycles per year.

WBC staff and volunteers refurbish the collected bicycles, making sure they are in good working condition. The organization welcomes people with minimal skills—"if you only know how to repair tires, we can use you"—and also trains people in bicycle repair.

Once about 500 bikes are ready and a recipient group is lined up, WBC schedules a work party to pack the bikes into a container. Each container is destined for a specific partner organization, which distributes the bicycles to individuals.

WBC is an excellent example of creative recycling, taking "waste" from our culture and converting it into usable treasure for another.

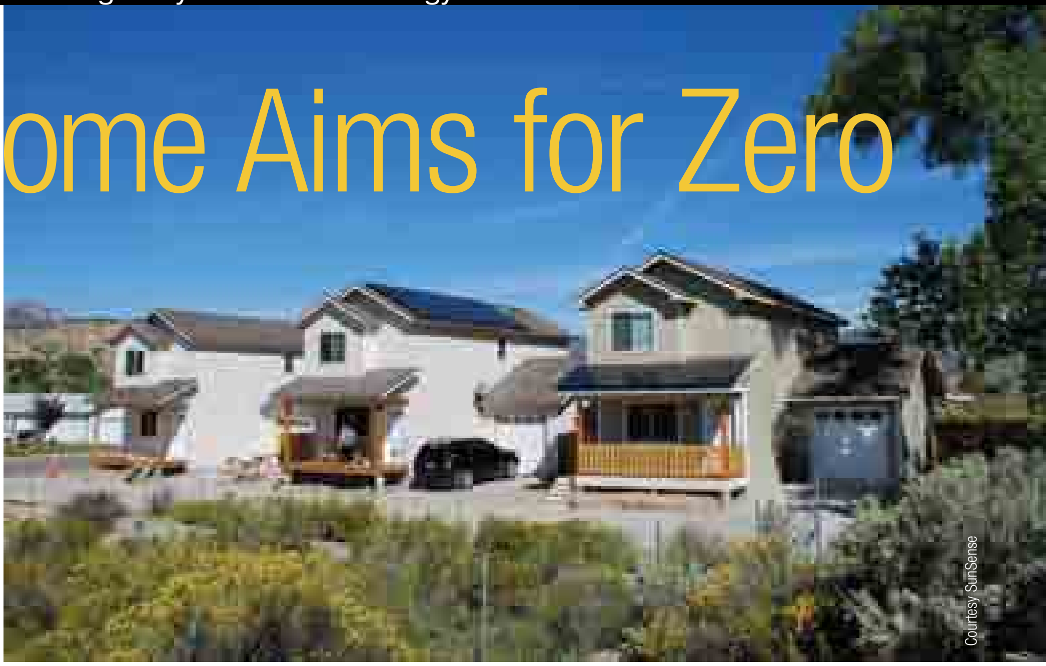
—Ian Woofenden

Pedal-Powered Machines

Besides providing functional, environmentally friendly trans–portation to those who can least afford it, WBC also designs and builds pedal-powered machines. A wide variety of creatively functional and delightfully educational devices, such as water pumps and blenders, have come out of the WBC's workshop. The organization demonstrates these devices at public events and provides guidance on how to design and build pedal-powered tools and art, with detailed instructions, parts lists, and clinics.

A pedal-powered blender in Guatemala.

Habitat Home Aims for Zero



The house on the right, with a 1.2 kW PV system on the south-facing porch roof, earned a HERS rating of 39. The middle house, with a 3.2 kW PV system on its east roof, scored a HERS rating of 25. The house on the left is planned to have 3.15 kW on its east and west roofs, and score a HERS rating of zero.

Habitat for Humanity of the Roaring Fork Valley in Colorado has been raising (actually lowering) the energy bar with every new home they build. Three of their latest homes in Rifle, Colorado, are receiving PV systems to further reduce their energy footprint. All three homes are 1,200 square feet and will have approximately three occupants.

Each home was designed with energy efficiency in mind, and was evaluated independently using the Home Energy Rating System (HERS)—a scoring system established by the Residential Energy Services Network. The lower a home's HERS index, the more energy efficient it is compared to the HERS reference home (which is based on the 2006 International Energy Conservation Code). Each 1-point decrease in the HERS index corresponds to a 1% reduction in energy consumption. A home with a HERS Index of 85 is 15% more energy efficient than the reference home, and an index of 80 is 20% more energy efficient. A net-zero home would have a HERS rating of 0.

As a part of the HERS scoring process, each house was modeled using REM/Rate home energy analysis software. Before PV systems were added, each home scored a HERS of 50. A 1.2 kW PV system will reduce the home's estimated annual energy cost by about 25%; the 3.15 kW PV system is projected to reduce annual energy costs by 54%.

Note that all three homes were oriented north/south to fit on their small lots, so passive solar gain couldn't be maximized. Due to a huge tree to the east of the first home, its south-facing porch roof was the "best" roof for PV array placement. Enphase microinverters were used because of their economy, ability to forego string sizing, and ease of installation. The second home's large, east-facing roof was chosen to accommodate a larger array (18 modules versus seven).

An even larger PV system—6.3 kW—will be installed on the third home, with 3.15 kW each on east and west roofs. This home is still under construction but is on track to becoming HERS zero-rated. Although the original design called for the same-sized PV system (also located on the east-facing roof, like the second home), once Habitat saw how close they were to building a net-zero house, they contacted the one of their major sponsors, utility Encana Oil & Gas, to donate additional funds to size a large-enough PV system to zero out its electric bill annually.

—Andy Lietz

Project Specs

Project name: Habitat for Humanity

System type: Batteryless grid-tied PV

Installer: Sunsense Solar

Date commissioned: 3/15/10; 7/27/10

Location: Rifle, CO

Latitude: 39.5°N

Resource: Solar

Average daily peak sun-hours: 5.5

System capacity: 1.2 kW; 3.2 kW STC

Average annual production (AC kWh): 1,987; 4,185

Average annual utility bill offset: 25%; 54%

Equipment Specs

Number of total modules: 7; 18

PV manufacturer and model: Suntech STP175S-24/Ab-1

Module rating: 175 W STC

Inverters: 7 Enphase M190-72 microinverters; Fronius IG3000

Rated inverter output: 190 W; 3,000 W

Array installation: Roof

Roofing material: Composite shingles

Array azimuth: 180°; 90°

Tilt angle: 26.5° (both)

Preparing for Winter

Is Your Off-Grid PV System Ready?

The winter season puts off-grid photovoltaic systems to the test: The energy demands are highest due to long, dark evenings, more indoor activities, greater heating needs, and fewer hours of sunshine. Before you're in the thick of a winter storm, use this to-do list to make sure your system is ready to face Jack Frost.

PV Array: Check the output of each PV module or module string. Use your system monitor or controller's display to observe its output. Turn off all module strings at your array combiner box, or unplug them if using quick-connect terminals. Then turn on one string at a time and check its output at the system monitor or controller's display while the others are offline—and then compare outputs. If a string or module is underperforming, this is the time to learn why and correct it. Inspect and tighten mounting bolts, terminals, and wiring.

Rack: Some racks can be adjusted seasonally for best year-around performance. The ideal tilt equals your location's latitude for spring and fall; latitude plus 15° for winter; and latitude minus 15º for summer. As summer usually brings an excess of PV energy, you may prefer to adjust to the "winter" angle for November through February, and then simply reset the angle to latitude for the rest of the year.

Tracker: Grease bearings and gears; check mounting bolts and shock absorber action.

Rebekah Younger

Engine Generator: Be sure that it is wired, tested, and ready. Check or change oil and filters. Make sure starting battery is strong and fully charged with clean connections.

Charge Controller: Check voltage set points—some can drift or reset to a default setting. Check that the external temperature sensor is firmly attached to a battery.

Wiring: Check for tight connections, blown fuses, rodent damage, and any signs of wire or terminal discoloration from overheating.

Grounding: Inspect ground wiring, rods, and connections.

Loads & Appliances: Check for "phantom loads" and inefficient usage. Clean refrigerator coils. Look for "load creep"—added summer loads that now threaten your winter energy budget.

Lights: Look for blackened compact fluorescents. Clean the dust from lights and fixtures.

Inverters: Check settings and connections. Test the inverter's battery charger settings by running the generator when batteries are below 80% charge, noting if it produces the current you should expect. Be sure the inverter is set for the type of battery you own (flooded or sealed), and that the generator is well-loaded but not overloaded. An inverter that won't stay steadily "latched" to its generator, but disconnects and reconnects, or trips the generator's output breaker, or can't hold steady rpm, is likely an overload.

Water Supply: Check for leaks, freeze protection, pump maintenance, and pressure tank precharge.

Flooded Batteries: Batteries will likely be your main focus for both maintenance and winter preparation. The more fully charged you keep your batteries, the better and longer they will serve you. Keeping them at a 40% to 80% state of charge for weeks in the winter will permanently damage them.

Test each cell or battery with a digital voltmeter or hydrometer to spot weak cells and potential failures. Clean or replace corroded connections. Lightly coat terminal components with commercial corrosion preventers or petroleum jelly, preferably while they are disassembled. Check for insect nests in vent pipes.

Check water levels and refill with distilled or deionized water. You will most likely only need to add water two to

four times per year—keep a log and you will soon learn how often. Near the end of their life, cells will use more water. Fill each cell to 1/4 in. below the bottom of the neck. Note that a fuller cell does not mean more energy; the plates of each cell must never be exposed to air, but the space above them is just reserve electrolyte.

Clean accumulated moisture and dust from battery tops. Batteries will dribble small amounts of electrolyte through the filler cap vent holes, especially if too full. This acid solution mixes with dust and dirt to form a conductive film that can leak current and weaken the battery. After equalizing or adding water, with the caps in place, clean the tops with a clean rag and old toothbrush moistened in a baking-soda-and-water solution. Never let the baking soda solution enter the cells, and throw out the rag and toothbrush when finished.

Initiate an equalization charge when necessary. Equalization is the deliberate overcharge of a full battery. It stirs up the electrolyte, breaks up light sulfation (which is what eventually wears a battery out), and evens out the chemical state of charge in each cell. Batteries may be equalized using either the charge controller or the inverter (and generator), or both together. Battery voltage should rise above 15.5 V (for a 12 V battery), 31 V (for a 24 V battery), or 62 V (for 48 V battery), and then stay there for three to four hours. Check the water level before equalizing. (For more information on battery maintenance and equalizing, see "Flooded Lead-Acid Battery Maintenance" by Richard Perez in *HP98*.)

—Allan Sindelar, Positive Energy, with portions revised from "Getting Ready for Winter" by Windy Dankoff in *HP14*

web extra

See **www.homepower.com/webextras** for guidance on generator sizing and loading.

Battery Safety

- Use safety goggles and rubber gloves when servicing batteries. Wear old clothes, because you *will* get acid on them—which makes holes. Keep an open box of baking soda and a plastic pan of water nearby while servicing your batteries—in case of a spill, you can dump the baking soda in the water, stir it, and use the mixture to quickly neutralize any spilled acid.
- Low voltage isn't a shock hazard, but high current is. A wrench dropped across terminals can quickly burn your hand and possibly explode the battery. Be careful!
- Even with the best care, batteries have a life expectancy ranging from five to 20 years. Increased water use, premature inverter shutoff due to low voltage, and voltage that rises too quickly when charging are all signs of failing batteries.

MMP Installation is Simple As

Mount the Backplate
Mount the BP-MMP backplate to the wall on 16 inch centers. The back plate is 16 ga. powder-coated steel and features ¼-20 pemnuts for fast installation of the inverter and MMP enclosure.

Install the MMP Enclosure
Start four of the supplied ¼-20 bolts into the pemnuts to mount the MMP enclosure. Four mounting keyholes allow you to simply place the enclosure over the bolts and tighten them without having to support the enclosure during installation.

Install the Inverter
Place the inverter/charger on top of the enclosure and secure with supplied bolts. The enclosure supports the weight of the inverter/charger, allowing one person to install a 60 lb inverter/charger without help. The DC positive and negative buss bars are preinstalled, connecting the DC once the inverter is in place. Connect the AC input and output wiring, battery cables, and optional DC breakers.

Attach the optional ME-RC or ME-ARC remote control to the front cover, install the front cover, and you're done.

MAGNUM ENERGY

To learn more about the MMP and other Magnum products visit www.magnumenergy.com

Wind Claims

Our local county is in a giddy state over the wind farm being proposed about 20 miles south of where I live, near Inkom, Idaho. They are promising to make Idaho a world leader in wind turbine technology, with hundreds of local jobs, and leasing a very large industrial building.

The reason for this excitement is in the promoter's application for a conditional use permit. Some of the buzzwords are: "95% efficient" (even though the Betz Limit defines the theoretical top limit of wind generator efficiency as 59.5%); "cheaper to build;" "makes more power in less wind;" and on and on. It is worth a read for the entertainment value, but unfortunately no one seems to be questioning the basic premise, which looks to me like totally fantasyland science fiction. In addition, our area has, at best, 8 to 9 mph average wind speeds, and the group has apparently done no anemometer testing.

I think of the old saying, "If you are going to tell a lie, tell a big one!" The claims of the promoters are so hyperbolic and removed from real life that I strongly believe the entire scheme is a well-thought-out plan to obtain investor funding and, possibly, state or federal grant funds. The "plan" now is that within six months or so they will have a prototype up. We'll see!

Courtesy Tom Simko

Also, I have attached an aerial photo I took of the Hoku Solar plant being built in my area to produce polysilicon for PV production. An acquaintance is the construction manager, and he tells me the daily worker population (just the construction crew) is more than 300. When finished, this facility will be Idaho Power's second-largest industrial customer! They had to run a major power line extension clear through town just for it. We would all like to think PV modules spring from the earth fully formed. Getting a good look at the major industrial processes involved is pretty amazing. A good title for this picture would be "No Free Lunch!"

Realism about all forms of energy and their costs, possibilities, and impacts will help us move forward with sensible solutions, locally, regionally, and nationally.

Tom Simko • Skyline Solar

EV Lesson

I loved the article about the electric vehicles in *HP139* ("The EV Revolution"). But it leaves me wondering if the automobile industry needs to take lessons from the forklift industry.

If a forklift can run in a 0°F freezer for seven hours on a single battery charge, why can't cars do better than they do? A big part of it is speed. Do we really need cars to run any faster than 80 mph? Top speed limits I know of are 70 or 75 mph. We take many local trips and don't exceed 40 mph.

Electric forklifts are designed *around* the battery pack, knowing the battery will be replaced or changed on average once a day. Perhaps the auto industry needs to come up with a standard voltage and size battery pack, and then have a slot on the cars where you pull the pack and swap it at charging stations based in different areas around the city, just like refueling at gas stations. Then, you could travel cross-country in electric-powered cars.

Darin Harp • Melber, Kentucky

EV critics have accused electric cars of being glorified golf carts, so it's critical that new models go every bit as fast as gas-powered cars—even if it means a slight hit in terms of driving range. The fact is that electric cars have tons of torque and can be extremely fast. That's a good thing for market acceptance.

In terms of standardizing electric car batteries across all manufacturers, that's a tough challenge. Better Place, the Silicon Valley start-up, is working on battery swapping in Israel, Denmark, and Japan. The company is using an electric car from Nissan-Renault. In relatively small markets, when the size

and shape of the vehicle and the batteries can be highly controlled, it might eventually work—although it's extremely expensive. In big open markets with numerous companies selling EVs, it's quite difficult. Keep in mind that the condition of any specific battery pack can change with use and time, creating inconsistencies between the battery you might swap out and the one you receive.

The key question is if battery swapping is necessary. Most electric car charging will take place at home or work, and can meet about all the needs of an average driver. That can be supplemented by a smattering of public quick chargers, able to juice up a battery pack to about 80% of its charge in 15 to 30 minutes, depending on a number of factors.

In the long term, there are all kinds of possibilities, including new generations of high-energy batteries. But we're ready right now with existing batteries and home charging to deploy millions of EVs across the United States.

Bradley Berman • www.hybridcars.com

Courtesy Dave Cozine

Monitoring

I read "Keeping Tabs on Your PV System" in *HP139* with great interest. The article is well-written and researched, but I am puzzled about one aspect. I am an information technology professional with 43 years experience and own a small PV system for backup electricity. I collect system performance data manually so I can keep tabs on my system. I have considered automating this by using a data-logging system.

What I do not understand from the article is why anyone would want to send the information over the Internet, unless one wants to remotely monitor a PV system. If data is collected at the site of generation, I do not see any reason to use the Internet. In fact I would not want my data on the Internet, since it's my private data. I cannot see any advantage in using the Internet versus keeping the datalogging system and information generated on a local workstation or home server. I would appreciate clarification of this issue.

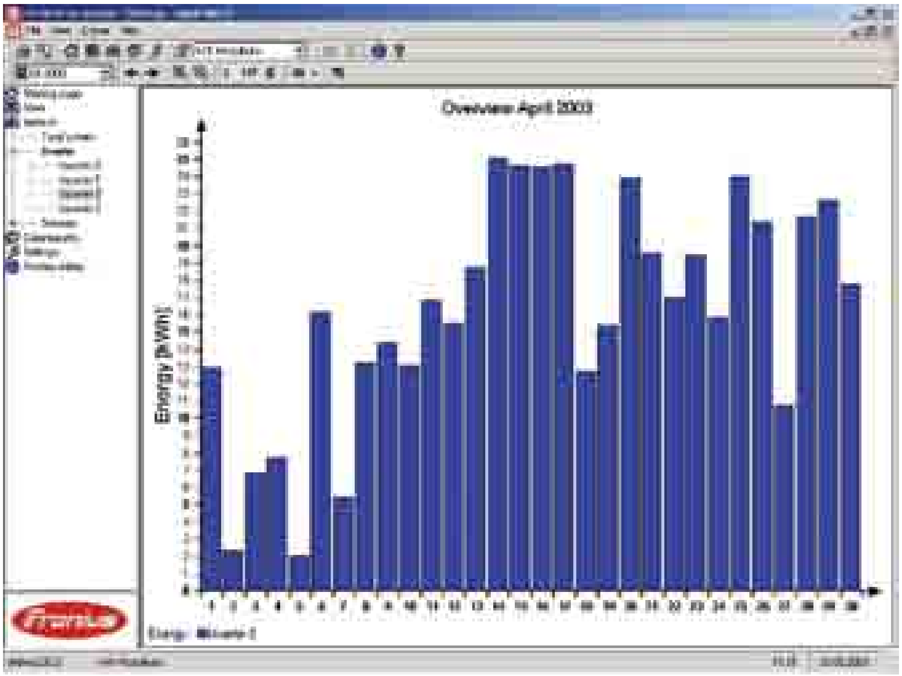
Thanks for the great article. *Home Power* gets better with each year.

Richard J. Molby, K3OE • via e-mail

Many RE users enjoy the convenience of accessing their system's data wherever Internet access is available, for curiosity and diagnostics. One user I spoke with diagnosed an inverter problem on his system in San Francisco while he was working in Malaysia.

Some people like the democratic nature of sharing production information with all, for education and improvement of the industry. Web-based data-logging systems give users choices about how much and what data is made public, of course, so those wishing to keep the information to themselves can still use these systems, but not share the data.

Ian Woofenden • Home Power *senior editor*



Courtesy Fronius

WA Module Clarification

On page 47 of *Ask the Experts* in *HP139*, we compared Washington-made modules to the best (highest-efficiency, 19.5%) module on the market, stating that the Washington-made modules are 40% less efficient. Washington-made, CEC-listed modules, which have efficiencies between 12.1% and 13.1%, compare more favorably when matched against *average* crystalline module efficiency, which is about 13.8%. Higher-efficiency models (14.3%) are now available. For more information on PV modules and power density, see "PV Purchasing: Top 10 Considerations" in this issue.

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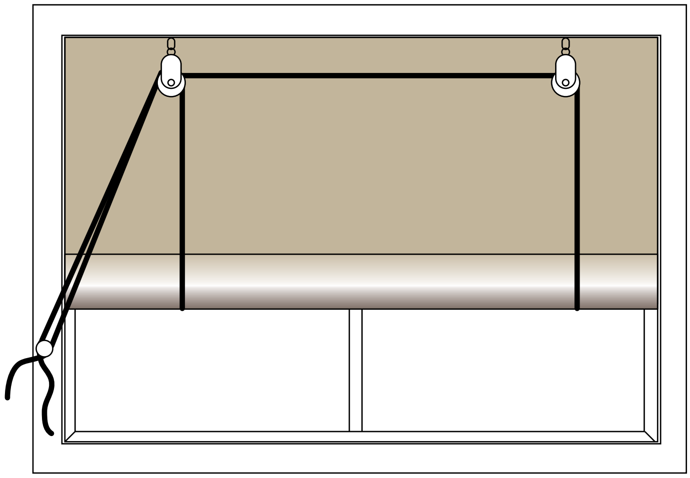
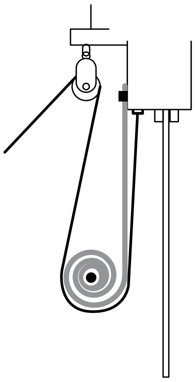
Insulated Window Shades

I've started to experiment with insulated window shades to improve the thermal performance of my home in rural Maine. Can you share some basic guidelines for designing and constructing low-budget, highly effective shades for my many windows? What materials are best? What is the best way to attach the shades to the window frame? One problem I've experienced when the existing shades are drawn is condensation and therefore frost building up on the inside of my windows. Is there any way to avoid this?

Ken Jones • Bridgton, Maine





Insulated shades can be great for keeping the warmth in and cold out (or vice versa). There are many options depending on what suits you and your windows. The most effective designs prevent warm, moist indoor air from contacting the cold window surface, which causes the condensation and frost buildup you mentioned. But ease of use and aesthetics are also important, as is durability and washability.

Window quilts can be made simply with fabric scraps and inexpensive batting, which will help, but there are options that can give better performance. After 30 years of trying various designs, this is what I've come up with for our many-windowed, passive solar, earth-sheltered house.

Quilt Layers

1. **Window-side cover:** Choose a fabric that will not degrade or fade in the sun if your shades will be down during the day (which is nice for hot summer days or for keeping a glaring winter sun out). You can go colorful or plain. I prefer unbleached muslin, pre-washed and shrunk. When rolled up, this is what will show inside and what will show through your windows from the outside when down, so consider those aesthetics.

2. **Insulation:**
   - "Thinsulate" polyester/olefin bat insulation is commonly used in active outdoor clothing. It has a fairly high R-value for its thickness and is known to stand up to active use and washing. Companies specializing in outdoor clothing fabrics are a good source for yardage. Choose the thin "Ultra" to keep your shade from being too bulky.
   - Insul-Bright is a thin, needle-punched polyester batting with a metalized poly film layer; it's commonly sold for potholders and crafts. It is washable and readily available. The metalized film reflects radiant energy, making this an effective window quilt material.

3. **Vapor Barrier:** You can tweak the insulative layers' performance by adding a vapor barrier on the "warm" side of the insulation. Common polyethylene film won't hold up to machine washing, so I use a silicone-coated nylon material that is popular for lightweight outdoor gear. Less expensive "seconds" can be purchased, which will suit this application.

4. **Inside Cover:** Many fabrics will work, and this can be an opportunity for creativity as long as the materials are washable and "wearable" (will not degrade with repeated washing, or rolling up and down). My early window shades were quite colorful, which, while interesting and cheery, tended to overwhelm the room when they were all down. I was happier with a plain white fabric that did a lot to brighten the room.

Quilting

High-quality materials that don't require a lot of quilting to hold together are important—you'll want to keep that loft intact. Tie or lightly quilt the whole sandwich together. Better yet, do it in two layers, attaching the two together with perimeter binding, which can be a separate piece, or simply fold over the inside or outside material and hem. Make narrow pockets the width of the quilt top and bottom to insert removable wood strips or dowels.

Installation

Performance will depend a lot on how well you seal the edges of your shade to the window frame to prevent warm, moist indoor air from circulating behind the shade and condensing on the cold window. I make my quilts large enough to snug up against the frames and long enough to sit easily on the sills. When installed on the face of a frame, they stay fairly close if there is a sill to sit on. This is my choice for ease of use versus highest performance, given the design of our windows.

A better seal that helps prevent airflow behind the shade can be made by making a U-shape track for the shade to run in. Or install a spring-hinged board that can snap over the quilt edges, holding them tight to the wall or frame. You could also make a non-rolling shade that attaches to the window frame all around with magnets or large snaps.

Make sure there is a generous air space between the shade and window so that the shade doesn't contact the window. Attach your quilt firmly at the top, tight against the wall or window frame. I make three holes through the material and top wood strip for screws, for easy installation and removal for washing.

Roll-up mechanisms can be made using cords and pulleys. One end of the cords is stapled behind the shade at the top, routed down, around the bottom, then up and through the two pulleys. Install small dowels or cleats nearby to wrap the cord around when the shade is rolled up.

Sue Robishaw • www.manytracks.com

write to:

asktheexperts@homepower.com

Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

Module Degradation

I've heard that solar-electric modules decrease in performance over the years. Why and how much? Does it vary with different PV technologies and brands? Is there anything that can be done to minimize it, or anything I should do to plan ahead for this degradation?

Joe Talbot • Charlotte, North Carolina

PV module performance decreases over time due to the aging or weathering of materials. Sunlight and heat will cause plastics used to encapsulate PV cells to lose their clarity, which blocks some of the sunlight. Performance can also drop due to mechanical failures, such as delamination of the plastic layers that protect the cells, or wiring or junction box sealant failure.

Well-made single-crystal silicon solar cell modules made during the 1980s degraded 1% to 2% per year. Today's crystalline modules degrade about 0.7% per year, which is why manufacturers give 25-year, 80% performance warranties with confidence. High-quality multicrystalline modules also degrade less than 1% per year, but after an initial 3% to 6% power loss during a light-induced degradation period of a few days in the sun. Amorphous silicon thin-film modules degrade more than 5% during their first few months in the sun. Afterward, degradation will level off to about 1% per year. Module manufacturers factor initial degradation into their power ratings and warranties.

You can prevent accelerated or unusual power degradation by allowing good airflow around the modules and by not concentrating or artificially focusing sunlight on them. This will slow degrading in the plastic parts and electrical connections. Keeping your modules clean also helps them operate at lower temperatures. During installation, handle and install modules carefully. Do not damage the modules' plastic backsheet, twist or distort the frame, or pull on junction boxes, wiring, or conduit.

You can plan for degradation by first recognizing that a loss of power is normal. If you are using crystalline PV module models that have been available for many years from well-established companies, you can use 0.5% to 0.7% per year degradation to estimate annual performance changes. For modules that do not have a track record, keep your 20-year to 30-year performance estimate conservative with a 1% per year degradation factor.


Courtesy Dan Fink, Buckville Energy Consulting

It is common for PV system designers to plan for long-term voltage degradation when determining the number of modules in series for a particular grid-tied inverter. When given a range of modules in series to choose from, they will aim toward the middle or upper end of that range. For example, if an inverter series-string-sizing program calculates that eight to 10 modules in series will be within the inverter's input voltage window, designers may go with nine or 10, so that after many years in the field, the string voltage will not stay within the inverter input range.

Joel Davidson • Solutions in Solar Electricity


iStockphoto.com

Tilting SHW Systems

We read a lot about tilt angles, changeable tilt, and tracking for solar-electric systems. What about solar water heating collectors? Would they be more effective if they could be tilted?

John Donaldson • via Facebook

A tilt angle equal to latitude makes the surface of collectors or modules perpendicular to the sun's rays on the equinoxes at noon, often appropriate for year-round production. Without clouds, haze, or smog, when the surfaces are perpendicular to the solar radiation, the most energy can be collected. Increased tilt angles favor winter production, and lower angles favor summer production. If the collection surface is tilted at an angle equal to latitude plus or minus 23.5°, the surface will be perpendicular to the sun at noon on the respective solstices.

There are two important differences in grid-tied solar-electric (PV) systems and solar hot water (SHW) systems that make adjusting the tilt of an SHW system unnecessary in most cases. First, the storage capability of SHW systems is finite; for grid-tied PV systems, it is infinite (sending surplus back to the utility).

Second, SHW collectors will produce close to twice as much usable heat in July as they do in January due to the increased ambient temperatures and solar irradiance. SHW systems produce much more energy with higher ambient temperatures while PV systems normally produce less—it's just the physics of the technologies.

Heat loss is a large factor in SHW collector efficiency and the higher summer ambient temperatures coupled with the increased irradiance make conditions ideal for heat production. Since the SHW storage is finite, summer overproduction can be a problem, while it's welcome production for grid-tied PV systems.

The NREL Redbook Manual of solar radiation data (http://rredc.nrel.gov/solar/pubs/redbook/) tells us that for a fixed tilt, most places in the United States will gather the most annual sunlight available with a tilt angle equal to latitude. A latitude tilt angle isn't always the best case for SHW, though. It is usually best if the SHW system design is estimated to produce no more than about 60% to 70% of the home's total water heating load, which will amount to about 100% of the load but not overheat in the summer. If the system is estimated to produce more than 60% to 70% of the load, it is preferable in most locations to tilt the collectors at latitude plus 15°. This optimizes production in winter (when SHW systems are more likely to fall short) and minimizes summer overheating. Systems for space heating have even greater summer overheating problems and are tilted at latitude plus 15° or a steeper angle.

In a few U.S. locations (parts of the Pacific Northwest, for example), the winter solar resource is so poor that the most annual sunlight can be gathered with a tilt angle equal to latitude minus 15°. In these locations, installers mount the collectors between latitude minus 15° and latitude.

Chuck Marken • *Solar thermal editor*

Wind Problems

My wife and I live in an off-grid house in southwest Utah. We have a 1.8 kW PV system and a 12-foot-diameter wind generator on a 40-foot, freestanding tower, and a propane generator for backup. The trees in the area are less than 20 feet tall, but we are on the leading edge of the crest of a ridge and "take the wind in the teeth" from a funnel effect.

Our area experiences very turbulent winds—from 0 mph to near-hurricane levels. Our Davis monitoring station typically reports winds in the 10 to 20 mph range, with gusts at 25 mph. During windstorms, we'll easily go 35+ mph, and sometimes up to 65 mph.

The wind turbine has been down for major repairs four times in less than two years. We have been turning off the generator at the controller (electric shutdown) when the wind monitor shows 35+ mph. I'm wondering if there's a "smart" wind controller on the market that could monitor the voltage (or some other indicator) and make decisions about [electronic] braking that could be input-selected? I also wonder if other "home-sized" units would suffer from similar problems due to our conditions?

Alan Brajnikoff • Kanarraville, Utah

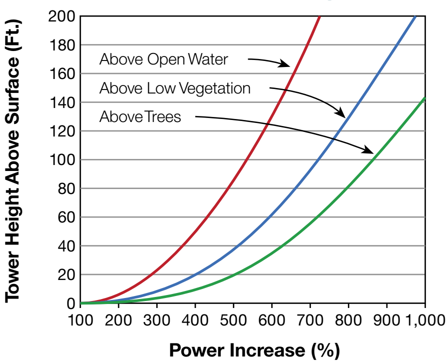
Your site sounds tough, which could be part of your problem. But your tower height is making the problem worse. At only 40 feet above the ground, you've put your turbine into one of the most turbulent zones, where winds shift rapidly both in direction and speed.

The standard industry rule is to site wind generators so that the lowest blade tip is *at least* 30 feet above anything within 500 feet. Higher is always better, both for wind quantity and quality. On your site, I would recommend an 80- to 100-foot tower. This will not only put your turbine into smoother wind, but will get into more energy-intensive winds, boosting your system's energy production and financial return. Remember that wind is a cubic resource, so increasing the average wind speed modestly can lead to very significant increases in wind-energy potential.

That said, if you have a heavy-duty resource, you will need a heavy-duty wind generator. You also need a wind generator that governs well and conservatively. High winds are relatively rare, so machines that maximize energy capture in moderate winds and protect themselves in higher winds will wring the most out of your investment. Your suggestion of automatic shutdown should not be necessary with a well-sited and well-designed turbine—most turbines will experience similar problems if placed in the extremely turbulent zone just above the treetops. Placing wind turbines on short towers is culprit No.1 when it comes to low production, wear and tear on machines, and customer dissatisfaction.

Ian Woofenden • *Home Power* senior editor

Power vs. Tower Height



PV PURCHASING

TOP 10 CONSIDERATIONS

by Justine Sanchez

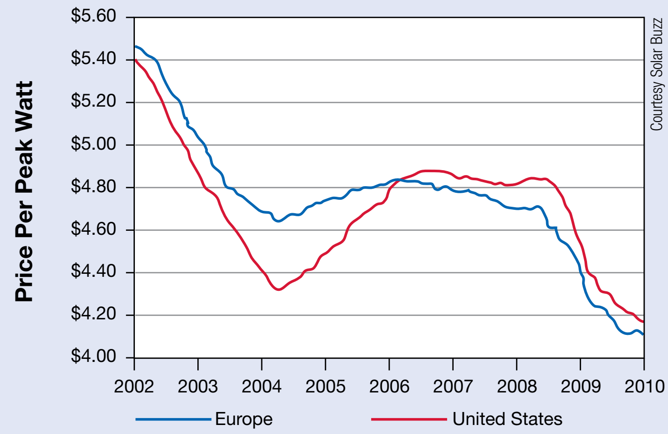
Shawn Schreiner

Cost. In the last few years, PV module prices have steadily declined. According to Solar Buzz, as of August 2010, the average retail price per watt was at $4.17. However, finding lower-cost, unblemished, UL-listed modules is fairly easy—we found modules as low as $2.50 per W from various online retailers.

While cost is an important consideration, shopping online and purchasing the lowest-cost modules may not be the best approach. Purchasing modules from an experienced and qualified PV designer/installer, while likely more expensive, will help ensure that a system is designed to meet your specific requirements and/or expectations, as well as a professional installation and support afterward. In fact, most reputable installers will only install the brands they are familiar with, and may not install systems purchased from an outside source. Additionally, some incentive programs require the system to be installed by a licensed/certified PV installer.

Module cost represents about 50% of the overall cost of a residential grid-tied PV system, which ranges from $5 to $8 per installed W. Economies of scale influence the cost as well. For example, the full cost of a 1 kW PV system might be at the upper end of that scale ($8,000), while a 10 kW system would be toward the lower end ($50,000).

Module Pricing



Warranty. Twenty- to 25-year power output warranties are standard in the PV industry, and material warranties range from two to 10 years. Material warranties often cover problems such as clouding or discoloration of the glass cover, delamination, poor solder connections, and failed bypass diodes.

Power warranties cover module power loss and are generally offered for 25 years. (Some of the items covered under material warranty are also covered under power warranty if those failures reduce power output.) Not all power output warranties are the same. For example, SolarWorld offers a "25-year linear performance guarantee." If during the first year, module output falls below 97% of rated output under standard test conditions (STC; 25°C cell temperature, 1,000 watts per m^2 irradiance), the company will replace the module. In subsequent years, if modules show a decrease of more than 0.7% per year (until the module is 25 years old), the company will also offer replacement. Often, other module power output warranties require that output fall below 90% within the first 10 years, or below 80% after year 10, to be considered for a warranty claim.

On the flip side, sending in a module for a warranty claim has drawbacks, including shipping costs and the potential for system downtime. When module shopping, ask the supplier how warranty claims are handled, what the typical shipping costs are and who pays for them, and if you have access to replacement/substitute modules to keep your system running should you need to return your modules.

Pinpointing Performance

Until recently, it was difficult to pinpoint individual modules in an array that produced less than their rated output. Array-level monitoring reports output data only in total kilowatts (and/or kWh) by the inverter display or a separate production meter. But module-level optimization and monitoring (such as from EiQ, Enphase, Exeltech, Solar Edge, or Tigo Energy products) can allow installers and homeowners to track the output of individual modules.

Without module-level data, identifying low-producing modules in residential-sized arrays, which commonly have at least 10 modules, can be difficult, since a 10% or 20% reduction in output from a single module only results in a small reduction in total output. (In a 10-module system, for example, you'll only see an overall performance loss of 1% or 2%.) Module-level monitoring allows system owners to compare each module with others in the array, and underperforming modules become easy to spot.

Module-level monitoring allows for quick comparisons between modules and makes identifying underperformers easy. Notice that modules No. 2 and No. 4 have significantly lower output than the others.

This Siemens module is still covered under warranty, even though the module line has twice been transferred, first to Shell Solar and then to SolarWorld.

Ben Root

Manufacturer History. Another factor to consider is the manufacturer's history in the business—how long have they been producing PV modules. Manufacturer longevity can be some indication of whether the manufacturer will be around for the duration of the warranty. While the future of PV module manufacturers is impossible to predict, manufacturers with longevity in the PV manufacturing business have worked out a lot of their production and design issues.

Be aware that shifts in the industry can have various outcomes. For example, the module line first produced by Astropower in Newark, Delaware, was taken over by GE Energy, and most recently bought by Motech. Unfortunately, GE Energy would not cover Astropower modules after it purchased the module line. Thankfully, Motech will honor GE module warranties, but Astropower module owners are still out of luck. In contrast, Arco's module line, acquired by Siemens, then Shell Solar, and now SolarWorld, has survived all these transitions with the company's warranty intact.

Cell Type & Efficiency. If you have limited mounting space, PV module efficiency is a key consideration. Modules with crystalline silicon PV cells—as opposed to thin-film—will likely be required, since thin-film modules produce about half of the wattage per square foot.

Within the crystalline module category, there are variances in power density (watts per square foot). Average power density is about 12.7 W per square foot, but some modules have higher power densities: Sanyo modules range from 14 W to 16 W per square foot; SunPower modules range from about 16 W to 18 W per square foot.

Using a module with higher power density means getting more power out of your usable mounting area. For example, let's say our shade-free mounting area measures 20 feet by 10 feet, for an area of 200 square feet. Without considering module dimensions, choosing a module with a 12 W per square foot power density will yield a 2,400 W array; selecting a module that yields 18 W per square foot results in a 3,600 W array—a 50% improvement.

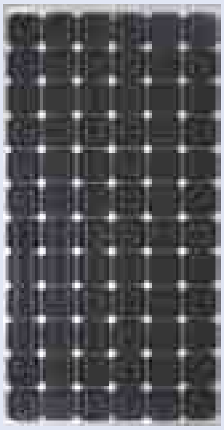
Roof Area Needed for PV Arrays

Roof Area (Sq. Ft.) per Array Size

Module Watts/ Sq. Ft.	1 kW	2 kW	4 kW	6 kW	8 kW
6	167	333	667	1,000	1,333
11	91	182	364	545	727
12	83	167	333	500	667
13	77	154	308	462	615
14	71	143	286	429	571
15	67	133	267	400	533
16	63	125	250	375	500
17	59	118	235	353	471
18	56	111	222	333	444

The downside is that modules with higher power densities typically are more expensive per watt (about 7% to 12% more). Decreased installation and racking costs for higher-efficiency modules may—or may not—amount to much. In most cases, if you have plenty of installation space, you won't likely want the more expensive modules.

Bifacial modules that produce power from both the front and back of the module (Sanyo's HIT 190 W and 195 W) report two values for module efficiency. These modules have clear backing, allowing some light to pass through, and can generate some energy from the reflective light that hits the back of the module. These modules can be good choices for awning and carport installations that can take advantage of reflected light.

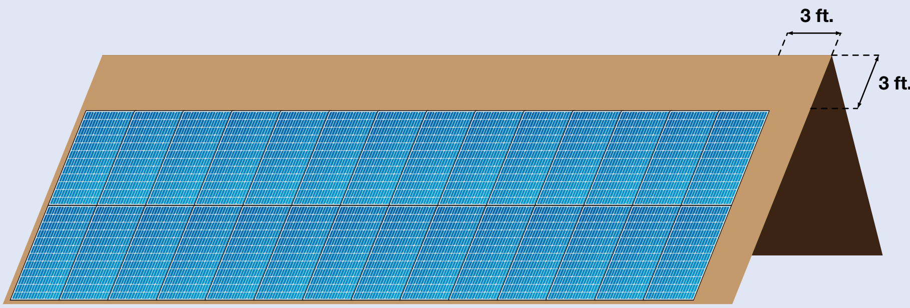


Courtesy Ningbo Solar Electric Power Company

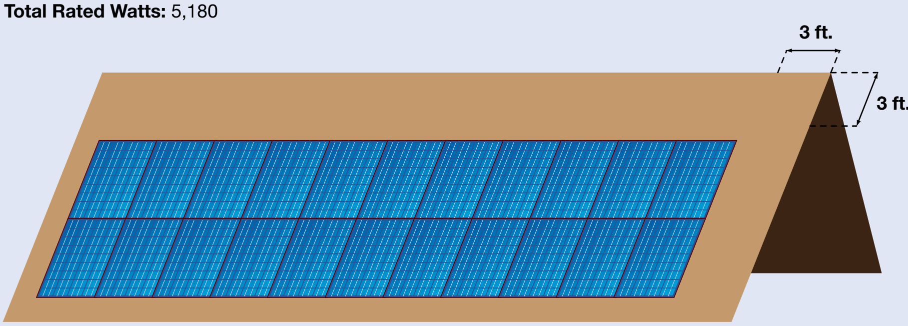
If there's plenty of room, then lower power-density modules, like this NBsolar 165 (12.9% efficiency), can be less expensive per watt.

Courtesy SunPower

At 19.5% efficiency, the SunPower E-19 318-watt module offers one of the highest power densities available.



Roof Dimensions: 41 ft. x 14 ft.
PV Array: Two series strings of 14 Trina 185 W modules for 28 total modules, each measuring 62.24 in. x 31.85 in.
Power Tolerance: +3/-0
Total Rated Watts: 5,180



Roof Dimensions: 41 ft. x 14 ft.
PV Array: Two series strings of 11 Yingli 185 W modules for 22 total modules, each measuring 51.57 in. x 38.98 in.
Power Tolerance: +/-3%
Total Rated Watts: 4,070

Module Size & Dimensions. This will determine array layout—how many modules can fit in the available space. Differing roof planes, such as trapezoids (created by hip roofs) require carefully choosing modules with appropriate dimensions, so that roof space is maximized without hanging modules off the roof's edges. Required setbacks for local fire department guidelines, accessibility for maintenance, module mounting infrastructure, and module interconnections and string layout will also influence what size modules will work in an array at your site.

Module sizes and dimensions need to be carefully considered to maximize roof space, while meeting local fire safety setbacks. The illustrations at left show the importance of comparing different module options. Both rooftops are the same size; both have arrays that use 185 W modules, but the modules have different dimensions. This results in the top left array having 27% more rated capacity. (Note: If modules were arranged in landscape orientation, the bottom array could accommodate 24 modules instead of 22.)

Power Tolerance. This is the variance from the module's rated output. For example, a 200 W module with a +/-5% power tolerance may produce anywhere between 190 and 210 W. Choosing modules with a positive-only power tolerance means the modules will at least perform to their rated specifications under STC, and possibly above. A 200 W module with a +10/-0 power tolerance is warranted to produce between 200 and 220 W. Because of higher output, they also may be appropriate for systems with limited installation space.

Pay close attention to power tolerance ratings: Some modules have both positive and negative ratings; others, like this Scheuten Multi-sol P6-54, rated at 0 to +10%, have positive-only power tolerances.

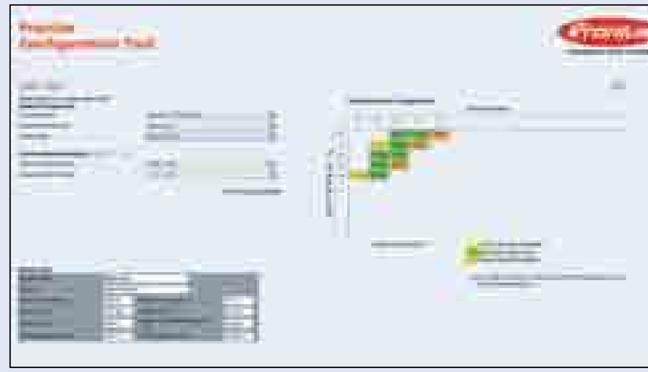
Courtesy Scheuten

web extra

Find specifications for currently available (100 W or larger, crystalline; 60 W or larger, thin-film) PV modules listed to UL-1703 requirements at www.homepower.com/webextras. Our listing includes only California Energy Commission (CEC) SB1 guidelines-compliant modules as of October 1, 2010, and module manufacturers that have a U.S.-based sales office.

Voltage Characteristics. This will vary between modules. Maximum power voltage (module voltage under load and at STC) ranges from 16.5 to 72.3 volts; and open-circuit voltage (module voltage when there is no electrical load and it is exposed to sunlight) ranges from 21.8 volts to 88.1 volts. These values are for STC module cell temperature. Below 25°C (77°F), module voltage increases. Above this temperature, module voltage decreases. This, coupled with the need for the array to stay within the grid-tied inverter's input voltage range, means that modules need to be selected and configured carefully.

String inverters operate at high DC voltages, and several modules are wired in series to achieve the voltage range of the inverter. Grid-tied inverter manufacturer Web sites usually include online array string configuration tools to help you figure out what module configurations you can use with each of their inverters. You can plug in various inverter models; PV module make and models; your mounting method (roof, pole, or ground-mount); and the site's high and low temperatures. The software then shows a range of how many modules are needed in each series string and how many of these series strings can be accommodated in parallel within the inverter specifications.



Courtesy www.fronius.com

Online string-sizing tools will determine how many PV modules and strings are needed to meet inverter capacity and voltage range.

Microinverter installations, where each module is directly coupled to its own inverter, must use compatible modules. Again, the inverter manufacturer aids by maintaining a list of modules that are compatible with each of their products.

Courtesy Solar Living Design

Some modules, like Sanyo's HITs, allow light to pass through the backsheet for underside lighting, as well as power generation from reflected light.

Module Frames & Backsheets. Frames are available in silver and black, and backsheets are either white, black, or clear (for bifacial modules), depending upon the manufacturer and model. If module aesthetics are important to you, you might minimize visual impact on a dark roof by considering modules with black frames and backsheets.

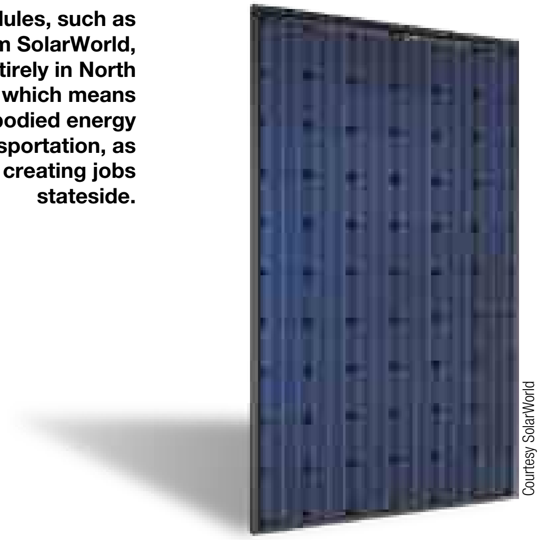
Courtesy SunPower

Manufacturers now offer more module options—like black frames and backsheets—to suit homeowners' aesthetic preferences.

Global & Local PV

Last August, the U.S. Department of Energy issued a six-month waiver to the "Buy American" clause for ARRA-funded public PV projects. Now, these projects use a more inclusive approach, using domestically manufactured modules containing foreign-manufactured cells or using foreign-manufactured modules, when comprised of 100% domestically manufactured cells.

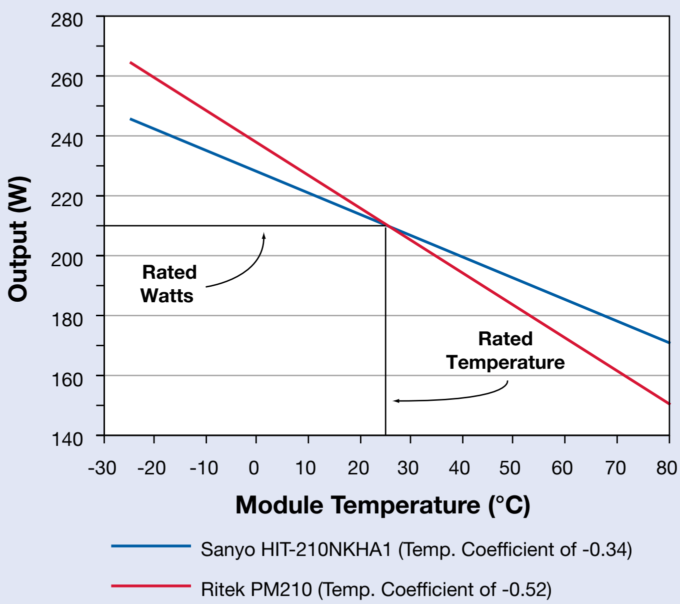
Some modules, such as this one from SolarWorld, are made entirely in North America, which means less embodied energy from transportation, as well as creating jobs stateside.



Manufacturing Location. This may be an important consideration for some, since the farther a module has to be shipped, the more "embodied energy" the module has. Additionally, jobs provided here in the United States by PV manufacturing facilities can help stimulate local economies. In an attempt to stimulate the U.S. economy, projects on public buildings that are a part of the federal American Recovery and Reinvestment Act of 2009 (ARRA) must use products that are manufactured in the United States. As a result, some modules (and other balance-of-system components) now carry the "ARRA Compliant" label.

Manufacturers including Evergreen, Schott, Sharp, and SolarWorld all have modules assembled in the United States. However, not every model is assembled here, and cells are often produced out of country. If you want to check if a specific module model or its cells were assembled in the United States, look for the "ARRA-compliant" label and/or contact the module manufacturer.

Effect of Temperature Coefficients on Power



J-Box, "PV Wire" & Other Installation Considerations

For ground-mounted systems operating at 30 V and above, in which the wiring is "accessible," raceways are necessary per *National Electrical Code* article 690.31(A). One way to satisfy this condition is by installing modules with junction boxes, which can accommodate conduit between the modules. There are only a few modules available with junction boxes (Sharp models ND-123UJF and ND-130UJF).

Systems using transformerless inverters, such as from Power One and SMA America, must be "ungrounded." Per *NEC* 690.35(D)(3), special "PV Wire" must be used if the module interconnects will be exposed. As a result, many module manufacturers are beginning to use "PV Wire" for their cabling.

For systems installed in hot climates, consider the module's maximum power temperature coefficient (Pmp temp coefficient: % per °C). The lower the value, the better it will perform at hotter temperatures. The Pmp temperature coefficient is usually about -0.5% per °C. Some modules have values of -0.3% or lower (Sanyo's HIT modules).

Access

Justine Sanchez (justine.sanchez@homepower.com) is a NABCEP-certified PV installer, *Home Power* technical editor, and Solar Energy International instructor who is currently pondering all these considerations as she is about to install another PV array at her house.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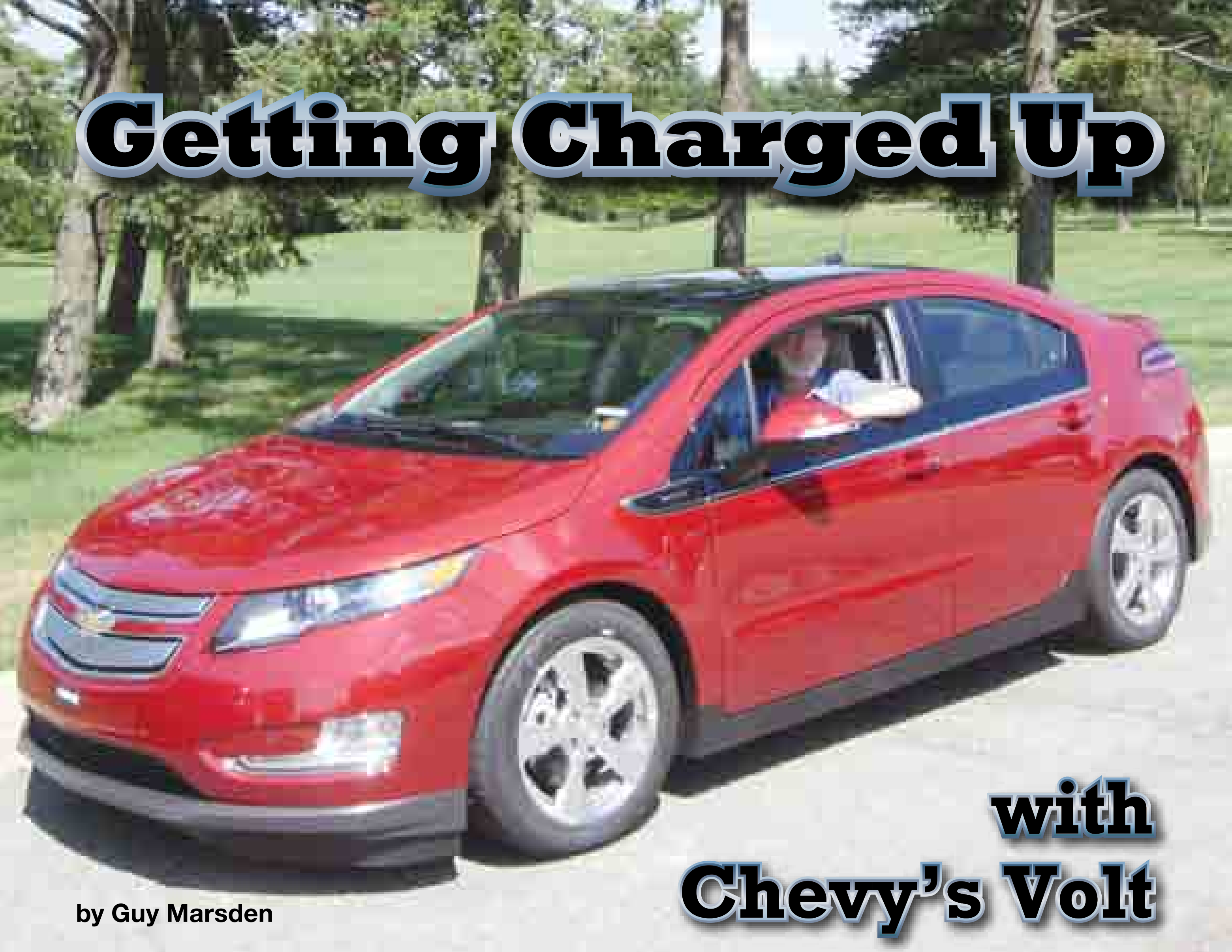
Getting Charged Up with Chevy's Volt

by Guy Marsden



Courtesy Rebekah Younger

The Volt is a new breed of mainstream-marketed vehicle that falls outside the existing paradigms of gas, electric vehicles (EVs), and hybrids as we know them. Unlike other hybrid-electric vehicles, the Volt can run exclusively on its electric motor—up to 40 miles of range—before its gasoline-powered generator kicks in to provide electrical energy for propulsion and to keep the battery maintained.

Aiming for the Middle

The General Motors (GM) design team wanted to create a vehicle that looked and felt comfortable and familiar. They were not targeting the fringe market of early adopters, but rather middle America—and the Volt hits this head-on. Although GM says it's the most efficient shape they've ever designed, the four-door sedan is styled typically for its class. Perhaps too much so—like the needless chrome grill on the front.

Bucket seats, two in front and two in back, seat four adults, each roomy enough to comfortably accommodate my 6-foot-1-inch frame. The rear seats fold down flat for useful cargo capacity, easily accessible through the hatchback.

The inside controls look like they were designed by aerospace engineers—with two graphic displays replacing traditional controls, the dash feels more like a 747 aircraft cockpit. The center console controls are backlit buttons that are all touch-sensitive—no "click" buttons here, it's digital driving!

web extra

I jumped at the chance when I heard that *Wired* magazine teamed up with Chevrolet Volt for a competition that allowed winners to test-drive its new car. My path to the winner's circle? A two-minute video that showed how my wife Rebekah and I use technology to reduce our carbon footprint: our solar heating, solar-electric system, and solar water heater; our two hybrid vehicles—a 2001 Honda Insight and 2006 Ford Escape Hybrid; plus my solar-charged electric lawn mower.

Check out Guy and Rebekah's solar tech at their Maine home by visiting www.homepower.com/webextras.

What Makes It Go

The Volt's propulsion is powered by a 400-pound, lithium-ion (Li-ion), liquid-cooled "T-pack" battery, developed and tested by GM, and manufactured by South Korean LG Chem in a new plant in Detroit. Li-ion compares favorably with the nickel metal hydride (NiMH) batteries used in most hybrid vehicles as it has more power and energy density, and longer cycle life. The T-shape places the battery down the center console from the engine compartment to behind the rear seats, where it spreads out under the rear cargo section.

GM worked with LG Chem on a proprietary chemistry and configuration for the battery. The 360-volt battery is assembled from more than 200 cells arranged in rectangular packs. Computers monitor at the cell level, allowing bad cells to be bypassed if they fail. (Most hybrid vehicles today use 1.2 V NiMH C cells wired in series/parallel to reach their operating voltage.) The batteries are kept at optimal operating temperatures by a liquid thermal-management system that both heats and cools the pack as needed.

The Volt's complete, T-shaped battery pack.

Courtesy www.gm.com (4)

This cutaway shows the Volt's battery placement—in the center channel of the chassis.

Fold-down seats and hatchback access provide ample cargo room. The Volt's charging cord tucks away neatly under the rear cargo area.

The charging plug makes sure the polarities are correct, and includes a small light for helping find the socket at night.

Courtesy Guy Marsden (2)

The Volt uses 8.8 kWh of its total 16 kWh battery, at which point the generator comes on. When battery capacity drops below 77% of what it was when new, it is no longer considered "automotive-grade." The company is investigating secondary markets for used batteries. The battery lab tests the batteries to extremes in environmental test chambers that can cycle from -90°F to 185°F and 10% to 98% humidity. They can simulate four seasons in two weeks and also do rigorous vibration testing on giant shake tables. This is one robust battery! It bolts to the chassis from underneath, and connects to the vehicle via a number of electric, computer, and coolant ports.

The Volt can be charged from a standard 120 V outlet in about 10 hours, and from a 240 V outlet in about four hours. A 120 V charging cable is provided under the rear hatch on a storage spool. The vehicle end of the cable is a SAE standard connector that incorporates an LED light to help you locate the port at night. A full charge requires 8 kWh, costing 80 cents, (at 10 cents per kWh). GM estimates that 35% of all Volts will be used in EV mode only, and 65% will need a partial charge each day to top off the battery. At 10 cents per kWh, Chevrolet estimates that driving costs for a Volt will be about one-sixth the cost of driving a gasoline-fueled vehicle. This battery charging could be provided by a solar-electric system as well.

Beyond Batteries

To satisfy many folks' desire for more than the Volt's 40-mile range, Chevy incorporated a gas-powered "range extender" to provide propulsion energy once the battery is depleted. The 53 kW gasoline generator does not recharge the battery, but maintains it at its minimum charge. Like other hybrids, the Volt seamlessly transitions from battery to engine/generator. So long as there's gas in the tank, you can continue driving, getting about 40 to 50 mpg. On a full tank of gasoline, the Volt can travel at least 300 miles after the battery is depleted.

Realizing that the gas could go bad in Volts that are driven less than 40 miles a day, engineers pressurized the fuel tank and programmed the car to run the gasoline engine occasionally to clear the lines and circulate engine fluids. While operating in EV mode and before the engine turns on, a warning appears on the console. The driver has the option of delaying this two times before the vehicle "insists" and runs the engine to lubricate parts and pressurize the system.

Efficiency in Design

We met with the Volt's exterior design manager, Young Kim, and the interior design manager, Tim Greig. Kim explained that weight was of secondary consideration to aerodynamics since you get better fuel economy improvements by improving airflow than by reducing weight. Although the chassis is steel, the use of plastics and carbon fiber materials keep the curb weight to about 3,500 pounds (average U.S. passenger vehicles weigh about 5,000 pounds). Unlike the 2,000-pound Honda Insight (the older, two-seat hybrid), which has an all-aluminum chassis and body, the Volt has an aluminum hood and a few other aluminum parts.

The Volt uses special 17-inch, all-weather tires to decrease rolling resistance, which increases fuel economy. Traction control and ABS brakes are standard. The braking system is responsive and aggressive. The regenerative braking is well-balanced with the standard disk brakes and feels as natural as in other hybrids. Regenerative braking helps extend battery life by making the propulsion motor act as a generator, slowing down the car while helping charge the battery, which also reduces brake wear. Drivers who have learned to optimize energy usage in hybrids will have no trouble adapting to the Volt.

Courtesy Guy Marsden (5)

In many ways, the Volt drives just like any ordinary sedan. Despite its lighter weight and special tires, the engineers assured us the Volt could handle our Maine winters. Our 2001 Honda Insight has done well in our northern neck of the woods, but we do fit it with snow tires in the winter. The only other issue is low ground clearance that can be a concern as snow piles up.

Monitoring

A 7-inch-diagonal LCD display replaces a typical instrument panel. According to GM, it's cheaper than a traditional instrument cluster. Graphics on the screen convey speed and range in miles for both electric and gas-supplemented modes. A green bar graph on the left shows miles remaining in EV mode. The graph color changes to blue when the range extender kicks in, at which point the range for the gas remaining in the tank is shown.

The Volt's efficiency monitor—an "orb" with three leaves on it—shifts up or down along a vertical axis, changing to amber at the extremes. The axis top represents acceleration; the bottom, braking. Accelerating or braking too aggressively causes the orb's position and color to change, giving you real-time feedback on your driving. (The ideal is to keep the orb green and in the middle.)

The center console's 7-inch display shows performance stats, such as miles driven in gas and electric modes, and combined miles driven per charge, along with miles per gallon per trip and cumulative miles driven. The screen is the entertainment center and climate-control user interface. An option includes a rear camera and parking assist package. When you back up, a grid overlay appears on the display, showing the vehicle's extrapolated track. As you turn the wheel, this track indicates where you will end up as you move back. Four proximity sensors along front and rear fenders activate a screen warning if you are closing in on an object below your line of sight. Getting used to looking at the console while backing up, rather than over your shoulder, will take some getting used to for most people.

Driving Performance

Driving the "crystal claret red" pre-production Volt on the Milford, Michigan, proving grounds was a blast! I experimented with all four driving "modes," starting with dropping into Low so I could optimize regenerative braking.

The console display shows performance and the Volt's accessories operation.

The dashboard display covers the operational items needed by the driver, and includes a performance-efficiency "orb."

Like any other vehicle, low gear is accessed from the shifter, but does not affect acceleration in any obvious way—when you let up on the accelerator, it just slows the vehicle aggressively using the regenerative braking.

The other modes are accessed from the Drive Mode button on the left of the center console. Two taps gets you from Normal into Sport Mode. In Normal, the car handles very well, but in Sport, you can pass with ease and leap onto the freeway like a sports car (0 to 60 mph in 8 to 9 seconds)—with the accompanying loss of battery reserve. It's no Tesla Roadster, but the change in power is palpable. Mountain Mode—three taps of the Drive Mode button from Normal—optimizes the Volt for long hill-climbing, activating the engine generator to maintain the battery. The sound of the gas engine was more noticeable in this mode and seemed to center at 3,000 to 4,000 rpm, distinct as a higher whine than in the normal range-extender mode.

The Volt takes hard turns very well and feels glued to the road due to its low center of gravity. The suspension is firm and responsive with minimal sway, balancing sedan comfort with a slightly sporty feel.

Although there's no operational reason for the range extender generator to vary its rpm, the design team felt that it was important to create a driving experience that felt familiar, so the rpm ramp up when you accelerate and wind down as you slow. I suggested that they create a user-accessible mode for "informed consumers," in which the generator speed is more stable and tracks battery level—and not user behavior.

Bells & Whistles

The Volt comes with a five-year OnStar package, GM's in-vehicle security, communications, navigation, and diagnostics system. GM's smartphone app (for Android, iPhone, and Blackberry) allows Volt users to check the charge level and to program plug-in charging times for off-peak rates. The smartphone interface also allows control of the climate control and locks, and gives stats like lifetime EV range, total range (with gas), average mpg, and total EV miles. For those without smartphones, OnStar will email a monthly diagnostic status report—it can even tell you if one of the tires is low.

Besides lock and unlock buttons, the remote key fob has two additional controls. One activates the charger, and the other activates the climate control to the last setting used. If the last setting was "economy," for instance, you can pre-warm (or cool) the car from the comfort of your home, just by pressing a button. The Volt is programmed to warm the seats first, then heat the cabin, all while plugged in and using grid power. That means no high-pollution engine idling to pre-warm the vehicle. One GM staffer said he felt that they had actually over-engineered the Volt. There are many nice touches that are only expected in luxury cars. These include USB charging ports and an MP3 port. Bose even designed a custom stereo system for the Volt that is both physically lighter and more efficient than traditional stereos.

On the downside, the list price of $41,000 could put the brakes on the Volt's potential to reach a wide market. Even after the $7,000 federal tax credit, a $34,000 car will have hefty monthly payments. However, GM is offering a three-year, lease-to-purchase option for $350 per month, which is quite competitive. The company anticipates the price dropping as larger-scale manufacturing helps decrease battery costs. And when the Volt becomes available in Maine in a year or more, we'll be first in line to lease one.

Access

Guy Marsden (guy@arttec.net) develops electronic products from his solar home. He operates ART TEC Solar, making differential temperature controllers for PV-powered solar thermal systems. See www.arttec.net for details of his sustainable lifestyle and business.

Chevy Volt • www.chevrolet.com/volt

GM-Volt • www.gm-volt.com • Independent site dedicated to the Volt

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The primary causes of positive plate deterioration are positive grid corrosion and positive active material wear-out or softening and shedding. These failure modes are the result of the normal overcharge required to fully charge batteries and to mix the electrolyte to prevent electrolyte stratification. In addition, batteries that are used in applications that require continuous float charging may be more susceptible to grid corrosion as a result of prolonged overcharging. Also, batteries that are subjected to frequent deep discharges (greater than 50% DOD) often exhibit increased effects from positive active material wear-out. This is usually the case in Renewable Energy applications. Testing at U.S.Battery has shown that an effective method for mitigating the effects of positive plate deterioration is to increase the ratio of positive to negative active material by ***adding a positive plate*** and removing a negative plate from a conventional cell design resulting in an Outside Positive (OSP™) cell design vs a conventional Outside Negative (OSN) cell design. This design approach results in a cell with increased positive to negative active material ratio, increased positive to negative grid ratio, and increased protection of the positive plate from positive plate deterioration. This results in longer life, increased capacity, and more stable performance over the life of the battery.

The only battery in its class with DEFENDER™ Moss Shields for longer reliable battery life.

Electrical shorting can be caused by 'mossing' shorts at the top of the cell element. These mossing shorts are the result of positive active material particles that have softened and shed from the positive plates, become suspended in the electrolyte, and eventually collect at the top of the cell element. Once enough of this material has collected to bridge the tops of the separators, it can contact both a positive and a negative plate where it converts to conductive lead and forms a short circuit resulting in cell and battery failure. This failure mode is more prevalent in stationary applications than in vehicular applications because of the absence of vibration and shock that normally dislodges the mossing material and causes it to fall to the bottom of the container where it collects innocuously in the mud cells. Testing at US Battery has shown that the use of insulating 'moss shields' in batteries used in these stationary applications can effectively prevent the formation of these mossing shorts. This results in longer life, increased capacity, and more stable performance over the life of the battery.

SPECIFICATIONS
RE L16 / 6-VOLT

AMP HOURS (100hr.rate)	441
AMP HOURS (20hr.rate)	401
AMP HOURS (5hr.rate)	332
MINUTES (@ 75 AMPS)	245
MINUTES (@ 25 AMPS)	915
LENGTH	11-7/8" (302mm)
WIDTH	7-1/8" (181mm)
HEIGHT	16-3/4" (425mm)

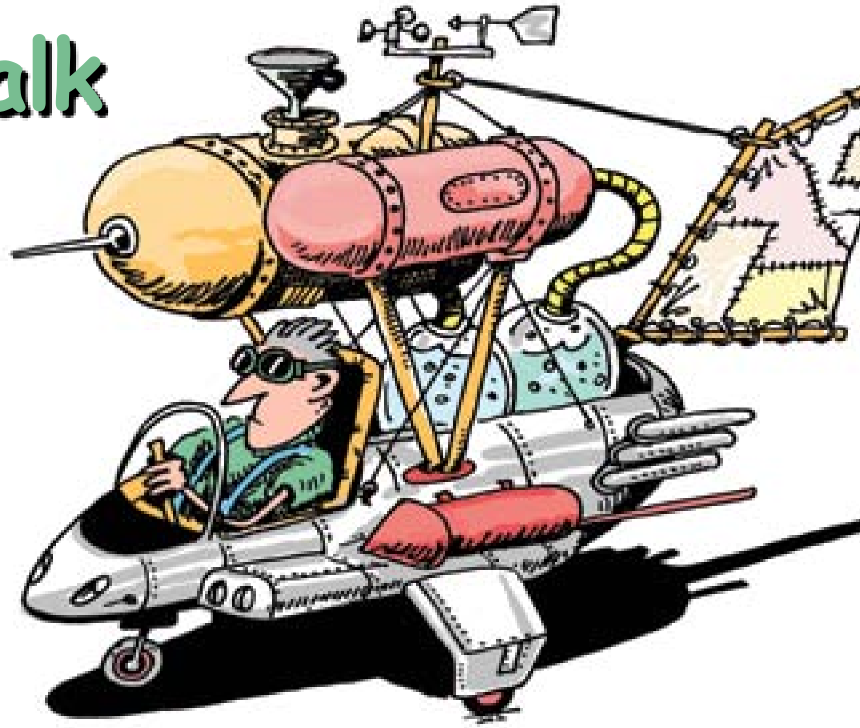
U.S.Battery Manufacturing Company

SEPA

RE SERIES

1-800-695-0945 WWW.USBATTERY.COM

Straight Talk



MYTHS IN MOTION

by Dominic Crea
illustrations by Harry Martin

If nothing else, the tragic Gulf oil spill of 2010 serves to remind us not only of how reliant we are on supplies of energy, but also, just how much we must endure to keep the supply flowing. But more than oil is spilling out of this chaos—whenever an event such as this takes place, all sorts of ideas, claims, and promises pour out as well.

Some of what's being proposed in the way of automotive technology is grounded on sensible physics and engineering know-how. However, there's just as much—perhaps more—bogus material creeping into the mix. Here, we attempt to separate fact from fiction.

The 150 mpg Carburetor

THE CLAIM: Engineers built a carburetor that would allow any automobile to get more than 150 mpg, but the oil companies or car manufacturers bought the patents and suppressed the technology.

THE TRUTH: Myth. Such a device is impossible.

The carburetor is fast becoming an automotive anachronism—like white-wall tires and eight-track tape players. A carburetor mixes gasoline and air in the proper proportion to combust in the cylinders of automobile engines—much as the lungs of our bodies mix air and "fuel" (carbohydrates) in the proper proportion to drive our own biological "engines." While carburetors can still be found in small-engine applications (e.g., lawn mowers), in automobiles, they've largely been supplanted by computer-controlled fuel-injection systems. The myth of the 150-mile "carb" is more interesting from a historical, rather than a practical, perspective. However, it's probably only a matter of time until, again, someone "invents" 150 mpg fuel injection.

Basic engineering and the laws of physics preclude such a device on theoretical grounds. However, a convincing proof can be provided quite easily without resorting to any of that high-brow stuff. Here's how: A typical car achieves about 25 to 35 mpg, but strapping one of these "wonder carburetors" on the engine purportedly increases this number to 150 mpg and beyond. We can infer that the increase in fuel economy scales with an increase in the total efficiency of the automobile's power train—in this particular case, we're looking at a four- or five-fold increase in efficiency. But this introduces a problem: Most engines are already operating at 25% efficiency—even a four- or five-fold increase in efficiency means that the engine is now operating at 100 to 125% efficiency!

A 100% efficient car means no waste heat, which then would require no cooling system. Radiators, water pumps, cooling fans—all become superfluous. Moreover, no heat means a cold car in the winter. True, you could burn some gasoline to provide some heat, but then, you would reduce your fuel economy as less energy is left to move the car. Get the idea? Oddly, believers in the 150-mpg carb always seem to avoid this logical discourse—and for good reason.

The carburetor is reasonably efficient at mixing fuel and air—fuel injection is even better. No doubt, improvements to either of these systems will continue to be made, but don't expect efficiency gains of more than a few percent, at most.

A Hydrogen Generator for Your Vehicle

THE CLAIM: An automotive generator small enough to fit in the trunk of a car can convert waste electricity into hydrogen gas.

THE TRUTH: Myth. There is no such thing as "waste" electricity. If an increase in fuel economy is your goal, skip any such devices and invest in a set of good tires and drive slower, instead.

All cars come equipped with an alternator to supply electricity for various purposes, such as lights. The automotive alternator operates on the same principle as the alternator in a wind generator: Rotary motion from the engine is transformed within the alternator (by spinning magnets or coils in a magnetic field) into good, old-fashioned electricity.

Over the years, proposals for tapping off some of that electricity and using it to split water into hydrogen gas by way of electrolysis have appeared and reappeared many times. Hydrogen, as we know, can be burned in engines. The faulty premise lurking in this myth is centered on alternator efficiency and that of all subsequent processes.

First, no alternator is 100% efficient—50% is about the best that can be expected from an automobile version—which means that for every gallon of gasoline that's burned to operate an alternator, half of that energy is immediately lost as heat. But that's only the start.

Converting electricity into hydrogen gas via electrolysis, while easy to do, is only about 80% efficient—tops. Moreover, the chemical-to-mechanical conversion efficiency attained with hydrogen fuel in a conventional engine is limited to about 30%. Of the energy *that could have been used to power the car directly*, something like 75% was wasted in these two steps alone.

The 150 mpg Plug-In Hybrid

THE CLAIM: Many popular hybrid cars on the market get about 150 miles per gallon.

THE TRUTH: While a 150 mpg plug-in hybrid may one day become a reality, the best of hybrids on the market today only get about 50 miles per gallon.

This claim is particularly irksome given its recent ubiquity. The fallacy is not one of technology but, rather, *terminology*—specifically, the term *miles per gallon* and the ambiguity that can arise in the context of plug-in hybrid vehicles. Such ambiguity is, however, avoidable if the general public will accept that hybrid cars require *hybrid* fuel economy ratings.

Here's how one form of the reckoning goes: Suppose you own a plug-in hybrid and decide to go on a 42-mile trip. You drive the first 40 miles in pure electric mode before exhausting the batteries. Then, the gas engine kicks in to complete the remaining 2 miles. Let's assume that the gas engine has a normal fuel economy of 25 mpg. This will make the calculation easier. Here's where things can get *creative*: If you take the total distance traveled and divide it *only* by the gas consumed, you arrive at an mpg rating of 525 mpg!

The source of this absurdity originates in the computation: One cannot arbitrarily ignore the electric energy in calculating the fuel economy. To do so invites all sorts of silly results. For example, a pure electric vehicle, consuming no *gas* whatsoever easily achieves an mpg rating of *infinity* by this reckoning.

To be fair, some officials are trying to come up with a metric that gives owners a sense of the mpg rating in terms of "gasoline-equivalent gallons." Unfortunately, even this approach has problems. In the end, what really makes sense is simply to state how far a vehicle will go on a gallon of gasoline or a kilowatt-hour of electricity—for both EVs and PHEVs.

A disturbing aspect of this myth is that more and more people are making similar claims for PHEVs. If this continues, the auto industry may have a lot of disgruntled buyers on their hands when they find out that their new car only went 40 miles on a gallon of gasoline—instead of *150 miles*—somewhere on a lonely stretch of road, say, in Wyoming.

Electric and plug-in electric vehicles are wonderful technologies. They promise to help wean us off fossil fuels if they derive most of their energy from renewable electricity. The technology is at our doorstep, but if we insist on providing a "gallon of gasoline equivalent" in hope of avoiding confusion, we will, ironically, do just the opposite.

Miracle Gas Pills

THE CLAIM: Miracle gas pills will increase your fuel economy.

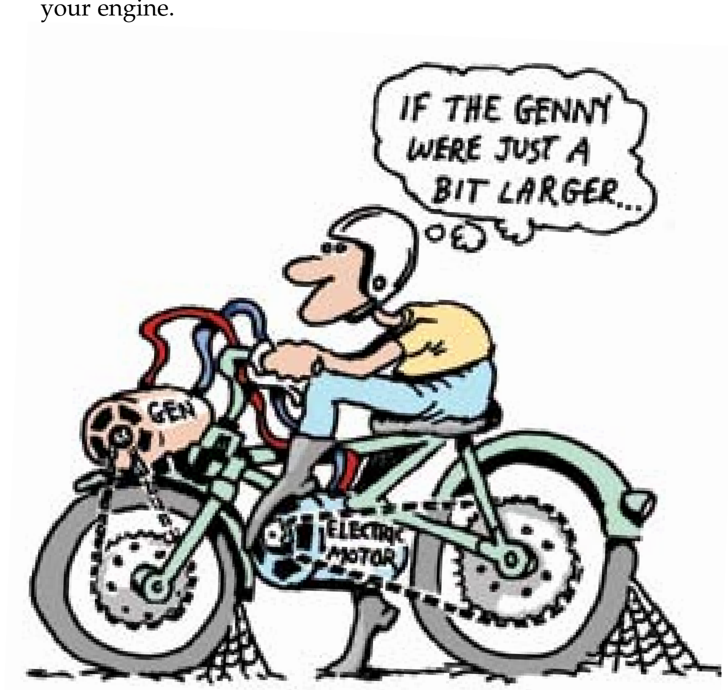
THE TRUTH: Myth. Avoid miracle gas pills and all variations thereof.

During a talk one year at a local energy fair, I picked up a pamphlet that read, "Miracle gas pills will increase your fuel economy by a guaranteed…"

The "miracle" pills were nothing more than solidified naphthalene—also known as *mothballs*—a hydrocarbon derived from coal tar. Yes, mothballs will burn when dissolved in gasoline; so will any number of soluble hydrocarbons, like two-cycle oil! True enough, these pills will increase the total distance you can drive on a gallon of gasoline—perhaps as much as one-hundredth of a mile.

Given the cost that some vendors are charging for this "product," you can figure on motoring down the road for a price that's easily as high as ten times what it would cost you to use ordinary gasoline.

And then there's the issue of what mothballs might do to your engine.



Perpetual Motion Machines

THE CLAIM: Perpetual motion or "free energy" machines provide more useful energy than they consume.

THE TRUTH: Myth. These machines are a hoax and unsubstantiated by tested established physical principles.

Sadly, this last myth has been around for nearly a century, and is one of the most damaging—especially to the pocketbooks of well-meaning investors. All of these machines claim to produce unlimited or vast amounts of energy from seemingly nowhere—a sort of bottomless pit of energy. Common buzzwords used by promoters are "magnetic," "over-unity," "quantum," and "dark energy."

One of the great triumphs of physics was the elucidation of the laws of thermodynamics. We'll focus on the first law: Energy, like the cookies in a cupboard, doesn't just appear or disappear into thin air. It may be transformed—taking another form like the extra pounds on our hips—but it is a constant quantity. If we take pains to account for all the transformations that energy can undergo, the total amount of all these forms in the end can never exceed what we started out with. This, in a nutshell, is a statement of the first law of thermodynamics.

Proponents of "free energy" tend to ignore this law, for obvious reasons. But when asked to provide proof of their claims for various "products," vendors invariably hem and haw with declarations like, "Our prototype unit is under repair, but we'll get back with you. In the meantime, for an investment of only a *few thousand dollars*…"

It's pretty clever when you think about it: No machine, but plenty of slick advertising to gain investors in a product that's "perpetually" under development.

The Simple Truth

There are many energy-related claims concerning automobiles—some true, some exaggerated, and some just downright bogus. Consumers interested in making smart choices need to be on their toes. All too often, a snazzy, sophisticated-sounding description is nothing more than a smoke screen for a product of dubious value. Do your homework, and keep close tabs on your wallet. Talk to professionals before making decisions that might turn out to be costly mistakes.

Access

Dominic Crea (dom120@juno.com) is a published author and the director of *Science Wonders*, an educational program devoted to helping people learn about and implement renewable lifestyles. He is a physics instructor at Oakland University and also teaches at the annual Midwest Renewable Energy Fair in Wisconsin.

Grid-Tied Inverter Applications

by Ryan Mayfield

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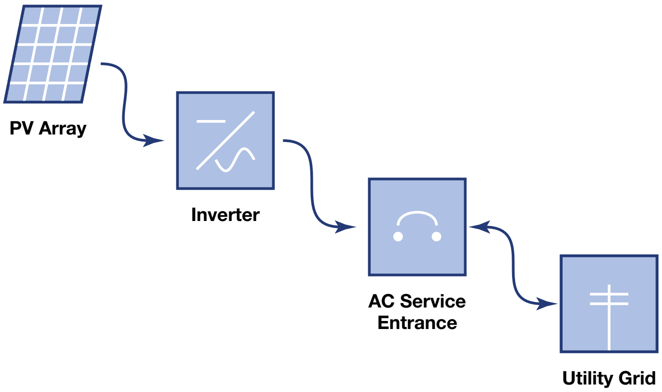
There's no need to go off-grid: Modern, grid-tied inverters let you keep the reliability of the utility, but allow you to produce your own, pollution-free energy with renewables.

While many of us fantasize about freeing ourselves from a lifetime of utility bills, the reality is that the grid is usually reliable and accessible. Most of us are already on-grid, so taking our homes off-grid doesn't make much environmental or economic sense. Today's modern grid-tied inverters make having renewable energy a snap. These systems are increasingly affordable and allow you to meet as much of your energy needs as you want—even annually zeroing out your electric bill.

How Do They Work?

Grid-tied (GT, utility-interactive, or UI) inverters actively "test" the grid and make operating decisions based on grid conditions. Even though some inverter manufacturers have GT inverters that resemble their stand-alone (off-grid) inverters, they function differently. There are two main types of GT inverters: *batteryless* and *battery-based*.

Batteryless Grid-Tied PV Simplicity



Batteryless grid-tied inverters

These inverters need the grid present to operate—except when they are installed in an AC-coupled system (see "Battery-Based AC Coupling" sidebar). These inverters make the simplest systems: the main components are the inverter and PV modules, plus safety disconnects (see "Simplicity" diagram).

This does not mean that the inverters themselves are simple—quite the opposite. Grid-tied inverters continuously perform complex tasks to keep the entire system operating efficiently and safely. The operation for these inverters is straightforward: when the sun is shining on the modules and the grid is present, the inverter accepts DC from the array, converts it to AC and synchronizes with the grid, pushing this energy into the electrical distribution system.

For a typical residential system, the inverter is connected to the main breaker panel along with all the home's loads. The PV system simply supplements the grid. The inverter pushes energy toward the grid, even while the loads in the home are drawing energy. If the PV array and inverter are producing less than the loads are consuming, the remainder comes from the grid. If the array produces enough energy to exceed the draw of the loads, the inverter sends the excess energy into the grid, "spinning" the utility kWh meter backward. Without sunlight, the array is not producing, so the utility resumes as the sole provider of electricity for the loads, running the meter forward again.

If the grid voltage or frequency goes outside UL1741 specifications, the inverter immediately disconnects itself from the house electrical system, and therefore from the grid. This process is extremely quick—the inverter will recognize the problem and disconnect before you even know there is an issue. Once the grid is within specification again for five continuous minutes, the inverter reconnects and resumes operation.

Reasons to Stay Connected

You don't have to go off-grid to produce your own energy. Modern, grid-tied renewable energy systems enable homeowners to generate enough energy each year to "zero-out" their electrical bills with clean, homemade electricity. Regardless of the system type you install—battery-backup or batteryless—keeping the utility offers many benefits:

- You can use the grid as your "backup," drawing power when you need it; and feeding power into it when your RE system's production is greater than your electrical use.
- Your renewable energy always has somewhere to go: either to your loads or to the grid. In off-grid systems, when the batteries are full, the RE isn't often fully utilized, "wasting" some of the energy potential.
- You can take advantage of utility, state, and federal incentives (rebates, tax credits, and tariffs) to offset system costs. In some states, RE-generated electricity is worth more than the average retail electric rate, enabling you to earn money with the energy your system produces.
- Grid-tied PV systems are about 20% to 30% more efficient than off-grid systems.
- You can size your array to offset any portion of your utility usage. While you can choose to "zero-out," you don't *have* to produce all of the energy you consume—you can simply install a system based on what you can afford or what you can fit at your location.

Inverter Safety

All GT inverters must be listed by a nationally recognized testing laboratory, such as Underwriters Laboratories (UL), Intertek (ETL), or Canadian Standards Association (CSA). Each of these organizations tests inverters to the same standard, UL1741. Within this standard, the exact requirements for the inverters are outlined to allow tests to be replicated among the various organizations. These safety tests give both consumers and utilities assurance that the inverters will operate safely when installed correctly.

One of the UL1741 tests is "anti-islanding." Islanding is when an inverter remains connected to the grid and sends power into the lines during a utility outage. This poses a hazard to workers, who may be repairing the lines—an unexpected source of power feeding those lines puts them at risk for injury. To prevent this, GT inverters have built-in safety switches, isolating them from the grid as soon as grid voltage or frequency goes off-specification. The inverter continues to monitor the grid; and once the grid has returned to normal operating conditions for five continuous minutes, the inverter resumes sending energy from the PV array to the grid.

The UL1741 testing also checks inverter equipment for components that reduce shock hazards, verifies that cabinet space is large enough for the wires that will be installed, and establishes safety labeling requirements, along with other safety requirements.

Batteryless inverters are the most popular choice because of their high efficiencies and low maintenance. There is very little user interaction with these inverters since they don't incorporate any components that require diligent maintenance, like batteries. This also helps keep the overall system costs lower. For most of us in locations where the grid is very stable and outages are short in duration, batteryless inverters are a great solution.

Courtesy Enphase

These Enphase microinverters are batteryless grid-tied inverters that are used singly with each PV module.

Shawn Schreiner

Even with external AC and DC disconnects and a production meter, a batteryless grid-tied PV system is simple, reliable, and efficient.

Backup Limitations

The battery backup load center is where the loads you want to run—with or without utility power—are connected. Commonly, only the critical loads are placed in this panel. Many people want to back up *all* their loads, but most don't have the energy-efficiency practices and knowledge of their energy use to run an entire home without the grid present. If not managed properly, loads would quickly deplete the batteries, eventually causing the system to shut down. For those who want whole-house backup in the event of a utility outage, an option is to incorporate an engine generator into the system (which also must have a listed and properly installed transfer switch to avoid islanding).

Inverter & System Efficiencies

The efficiency at which an inverter can convert DC to AC receives a lot of attention. All inverter manufacturers proudly report the peak efficiency values on their specification sheets—the ability of these machines to operate at efficiency values greater than 95% is impressive. Although knowing the peak efficiency number is helpful, it doesn't reflect typical operation with varying PV output and utility voltages. Because of this, the California Energy Commission (CEC) requires inverter manufacturers to also provide "weighted" efficiency values, which are just as helpful to installers and end users in other states. Independent testing agencies follow the CEC protocol to test inverters, varying the DC input power and voltage values. The CEC publishes these values, with links on their Web site to the testing data.

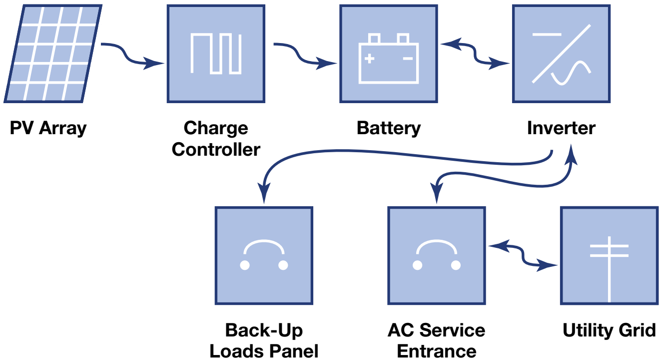
Batteryless inverters have higher efficiencies than their battery-based counterparts. But inverter efficiency only tells part of the story. Overall system efficiency should be evaluated and considered for true comparison between the system types. In addition to lower inverter efficiencies, battery-based inverters operate at lower voltages (potentially higher voltage-drop), battery charging losses, and losses associated with the charge controller and inverter operating separately. A batteryless system isn't without its inefficiencies; battery-based systems just have more that add up.

Backup Inverters

Batteryless systems' inability to operate without the grid can be a drawback. Some people have loads that need continuous power—like medical equipment, refrigeration, or lighting. For those folks, battery backup inverters are necessary. These inverters are connected to batteries, which store energy to back up the grid. Although batteries are not the only option available, they are the most reliable and economical choice for these systems. Devices like flywheels and supercapacitors are being developed and tested. For now, deep-cycle batteries are the best solution for PV systems that need energy storage.

Battery-based inverters are subject to the same safety regulations as batteryless inverters so they can be interconnected to the utility grid. These inverters and the systems they are connected to are more complex than batteryless systems. In addition to all the components in a batteryless system, a battery-based system requires a charge controller, batteries, and a backup load center. These components, plus the addition of a maintenance item—the batteries—add cost and complexity to these systems. (See "Grid-Tied…with Backup" and "Sizing a Grid-Tied PV System…with Battery Backup" in *HP139*.)

Grid-Tied PV With Battery Backup Adds Complexity & Inefficiencies



The operation of a grid-tied, battery backup inverter is very similar to a batteryless inverter. The only difference is that the inverter uses a small amount of energy to keep the batteries fully charged in case of an outage.

In the event of a utility outage, day or night, the inverter recognizes the outage and, like the batteryless inverter, immediately disconnects itself from the utility grid. At the same time, the inverter will begin to draw DC energy from the batteries (and PV array in daylight), converting it to AC for the backup loads. This happens very quickly (within 34 milliseconds) and, if already on, computers and all but the most sensitive electrical backup loads will continue to operate without a hiccup. Once the grid is back in operation, the inverter will reconnect to it and begin normal operation. Then the inverters can start recharging the batteries, readying them for future power outages.

For prolonged outages, one of the benefits of these systems (as opposed to a simple UPS with no PV) is the ability to use the PV array as a battery-charging source. If the utility is out for multiple days (and the sun is shining), the PV array

web extra

For comprehensive coverage of inverters used in PV applications, see "Inverter Basics" in *HP134.*

Courtesy Honey Electric Solar

A battery-based system has many more components—and therefore higher cost and maintenance—than a simple batteryless system.

can recharge the battery bank during that time. Of course, if the power outage happens during a winter storm and there is little or no solar resource during that outage, the PV array will contribute very little to the battery bank.

The extra system cost and added maintenance of batteries are the two biggest drawbacks for this type of system. For people who endure prolonged power outages, the peace of mind may well be worth the cost and maintenance time.

Considering the Right System

Knowing basic system operations and your particular requirements will help decide which type of GT system is right for you. This can come down to answering a few questions about your needs: How often does the power go out? How long is the typical outage? What loads are absolutely necessary during outages? How much maintenance are you willing to perform on the system? How much can you budget to cover system costs?

If outages are more than a minor annoyance and you can handle some battery maintenance, such as checking battery

Batteryless vs. Battery-Based Systems

	Batteryless	Battery-Based
Power when grid is down	No	Yes
Cost	Less Expensive	More Expensive
Efficiency	Higher	Lower
Design	Simple & Flexible	Complex
Installation	Simple	More Complex
Maintenance	Very Little	Batteries

Battery-Based AC Coupling

In traditional battery-based PV systems, the components associated with battery charging are all connected together on the DC side of the system—the PV array connects to a charge controller which is connected to the battery bank. This has some cost advantages, such as only needing one inverter. These systems also have some limitations, particularly with the maximum PV system voltage and the distance between the PV array and the balance of system components (i.e., charge controller, inverter, battery bank, etc). The PV array voltage will be limited by the charge controller; most charge controllers can accept between 150 and 250 VDC from the PV array.

To overcome losses from long distances, the wire size between the PV array and battery bank can be increased—but that adds cost. Another option is to AC-couple the PV array. This means connecting the PV array to a batteryless inverter, which can accept much higher voltage (up to 600 VDC), which reduces the array current, so that smaller-diameter wire can be used for long wire runs. The AC output from this inverter is then connected to a backup subpanel. A second, battery-based inverter is also connected to this subpanel. The battery-based inverter provides the stable AC power source that the batteryless inverter needs to operate. It is then up to the battery-based inverter to properly connect to the utility grid and charge the batteries—in essence it manages the batteryless inverter.

This solution can be used both in utility-interactive and stand-alone systems (see *HP133*, page 43, for an example of an off-grid AC-coupled system schematic). When used on the utility grid, it is critical that the battery-based inverter is properly listed to UL1741 standards for utility interconnection. While it is technically possible to connect nearly any batteryless inverter to a properly listed battery backup inverter, there is only one inverter designed to fully function in this capacity—SMA America's Sunny Island. The Sunny Island allows the battery-based inverter to directly communicate with the batteryless inverter and properly manages the energy flow. Other configurations require the use of external relays and controls to ensure the battery bank is properly protected from overcharging.

Sunny Island (yellow) and Sunny Boy (red) inverters in an AC-coupled system.

Courtesy SMA America

Incorporating an Engine Generator

For some, installing a PV system and not being able back up loads is unacceptable. One option to avoid the cost and inefficiency of batteries in a GT system is to install an engine generator. But how an engine generator is installed and works in conjunction with your PV system is a very important consideration.

For batteryless inverters, it is important to include a transfer switch so that the inverter never “sees” the AC output from the generator, and so the generator does not feed into the grid. During a power outage, the generator could automatically turn on to serve the loads. If the generator and inverter weren’t electrically separated, the inverter may try to connect to the generator, as if the generator was the grid. This could damage the generator and could result in an explosive and flame-filled ending.

The transfer switch allows the loads to be connected to either source—grid or generator—but never both at the same time. To avoid allowing the inverter to connect to the generator, the inverter should always be connected to the utility side of the transfer switch. This will make sure that the inverter and the grid are properly protected from the generator output.

With some battery-based inverters, it is possible to connect the generator directly to the inverter, just like a stand-alone system, and isolate it from the grid without an additional transfer switch. The inverter is limited by the amount of current it can pass through and fully utilize. This means you need to analyze the specifications for the inverter and match them to a generator. Other inverters require incorporating a manual transfer switch—you select the power source (grid or generator), then make some changes to the inverter’s programming to verify proper operation. Others can handle all those functions automatically.

cables, exercising the batteries, and regularly checking electrolyte levels (not necessary if using sealed batteries), a battery backup system may be the best choice. For most, the utility service in their area is reliable and outages are short and rare. In these situations, a batteryless inverter will result in overall higher energy yields and a simplified system.

Access

Ryan Mayfield (ryan@renewableassociates.com) is a NABCEP-certified PV installer and ISPQ Affiliated Master Trainer. When he isn’t trying to absorb all things solar, he is busy trying to influence the next generation by helping his kids solarize their backyard forts.

California Energy Commission • www.gosolarcalifornia.org • Listing of California-eligible RE equipment, including the state’s additional inverter specifications

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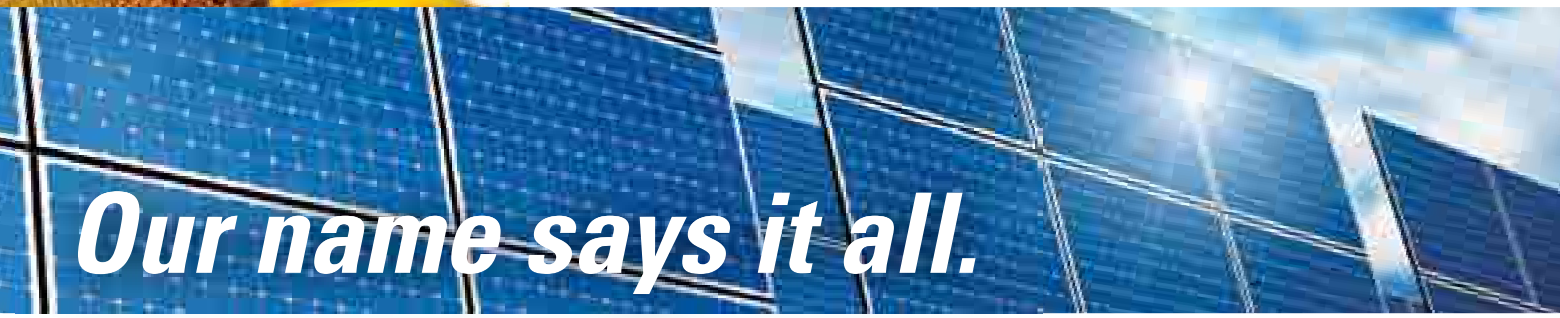

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Meet Jonathan.
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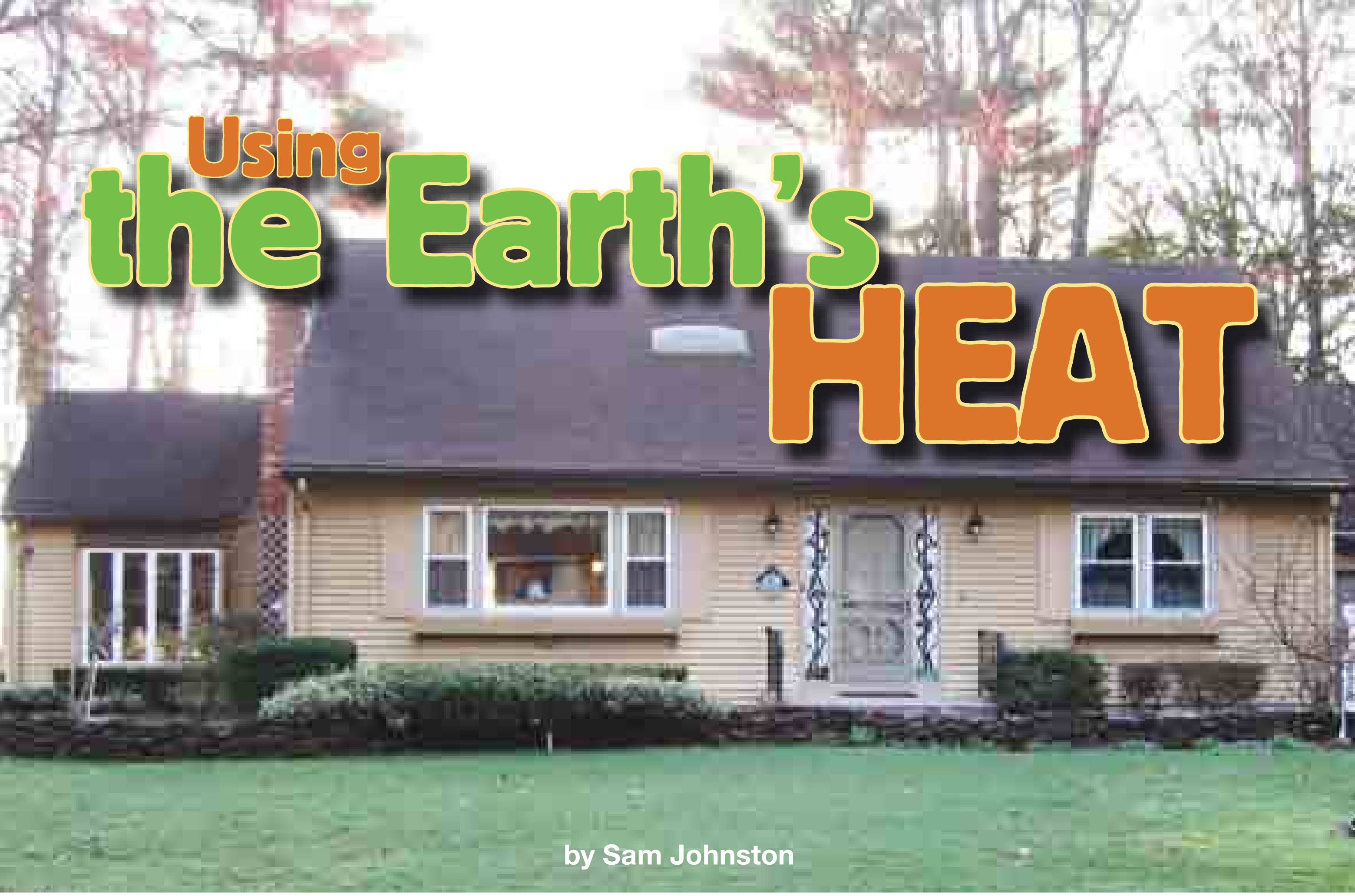
Also known as Triple J, Jonathan is as knowledgeable about off-grid PV as he is passionate about changing the energy paradigm. If you have a question about off-grid, remote water pumping or energy efficient industrial lighting, he's your guy.

Using the Earth's HEAT

by Sam Johnston



Courtesy Terraclime Geothermal (2)

Where does the heating energy come from for this home? Underground—where the constant temperature of the earth is absorbed and transferred to heat or cool the home.

Ground-source heat pumps use the stable temperature of the ground to heat, cool, and provide hot water for homes and businesses.

Gary Prior, an avid follower of renewable energy, decided to tap into this source for both philosophical and economic reasons. His family reduced its annual space and water heating expenses from $3,300 to less than $600. The 3-ton system also provides central air-conditioning and dehumidification that the home did not have previously.

How it Works

Ground-source heat pumps (GSHPs; sometimes termed "geothermal" by the heat pump industry) take advantage of the earth's steady subsurface temperature year-round. No matter if you are in Alaska or Arizona, the temperature 6 feet underground remains fairly constant. In New England, for instance, the earth's subsurface temperature is between 52 and 54°F. If you've ever gone into a cave on a warm day, you've probably noticed that the cave temperature is much cooler than outside. When the weather is cool, that same cave would be warmer than the outside air.

GSHPs use heat-transfer fluids (refrigerants) that have a low boiling temperature, so they can easily change from liquid to vapor and back again, transferring the energy from, or to, the earth's subsurface. Pipes (called a loop) drilled or buried in the ground circulate the refrigerants to transfer the heat in the ground to the heat pump. There, the heat is extracted from vaporized refrigerants and sent to a heat

Drilling vertical wells for heat pump systems takes little room and has little impact on the landscaping.

exchanger or air handler to heat water and/or air, which is then used to heat the house, either via a hydronic system or fan-forced, ducted system (see the "Distributing the Energy" sidebar). This process is reversed to cool the house, dumping excess interior heat into the ground.

In extreme weather—either very hot or very cold—a backup system may be needed to supplement the heating or cooling. However, with a properly sized system, most owners of GSHPs rarely turn to supplemental heating or cooling.

Heat Pump Variations

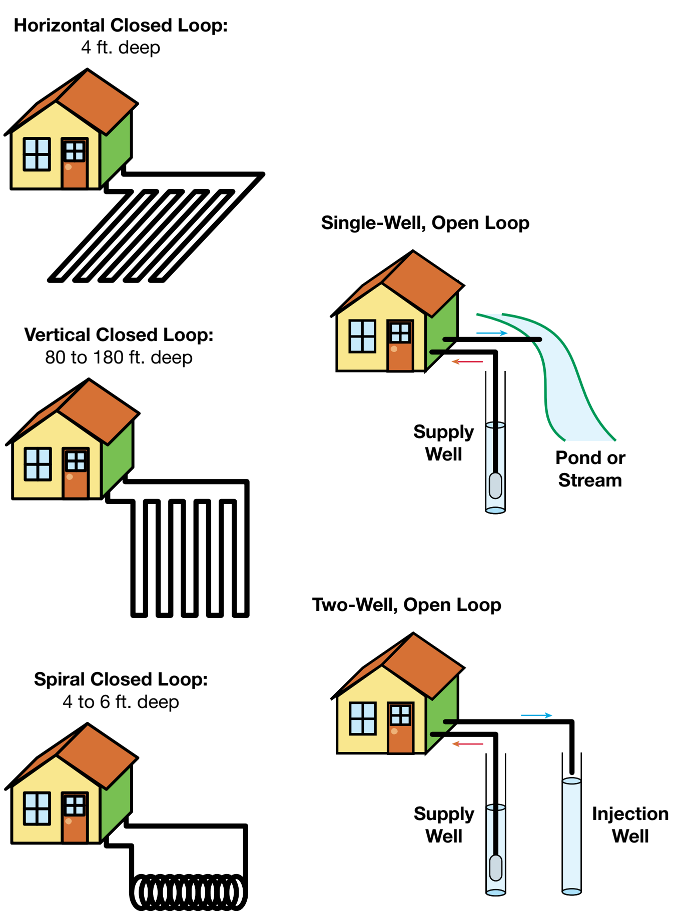
GSHPs use fluids to either directly or indirectly cause a refrigerant to change its state—that is, change from a liquid to a gas (taking on heat from the earth) or from a gas to a liquid (giving heat back to the earth)—similar to how a refrigerator works. These heat-transfer fluids (refrigerants) have low boiling temperatures. GSHP systems are either closed- or open-loop. Closed-loop systems typically circulate a propylene glycol and water solution through pipes in the ground and to the heat exchanger. There are several variations of closed-loop systems which differ in the orientation of pipes to the ground: vertical and horizontal (trenched, pit, and wide trench slinky).

Open-loop systems, nicknamed "pump 'n' dumps," use a body of water, usually a well or a pond, as the heat source and heat sink. The pond or well's water is circulated through the heat exchanger and then dumped back into the same water source. One type of open-loop system is the standing column well, where cold water is pumped from the bottom of a deep rock well into a heat pump, and then returned warmer to the top of the well, where, as it diffuses, the water returns to its original temperature.

Closed- vs. Open-Loop Heat Pump Systems

System	Pros	Cons
Closed-loop	• Can be installed almost anywhere • Fewer maintenance issues • Less temperamental	• Earth is not as good of a conductor • Less energy per foot of loop
Open-loop	• More energy per foot of loop • Water is a better conductor of energy than earth	• More maintenance issues • Could have local environmental risks • Requires lake or well nearby • More complex

Ground-Source Heat Pumps



Making the Switch

Before installing their GSHP, the Priors' 1975, 2,100-square-foot home relied on fuel oil for space and water heating. A heat pump was a good solution to both stabilize energy costs and decrease the family's reliance on non-renewable resources.

Once the Priors decided to make the switch, their home's envelope was assessed for ways to increase the home's efficiency and heat retention. The assessment encouraged them to add insulation in the attic. Additionally, they had their ducts inspected, and found they could upgrade their system to move air more efficiently, thus decreasing the size of the heat pump needed.

The entire heat-pump installation—digging and drilling for the loops—took two days. The drilling process includes:

Determining bore pattern. The drilling must be strategically laid out to avoid obstacles such as septic systems, utility lines, property boundaries, and boulders.

Drilling. Most GSHP installers hire contractors to drill according to specifications. When choosing a company to install your GSHP, ask about its relationship with drillers.

Fill and rough grade. After the ground loop is laid, the ground is filled and leveled back to original.

After drilling, a team of heat pump installers put in the air handler and GSHP in about three days.

Comparing Heaters' Fuel Costs

Fuel	Fuel Unit	Price Per Fuel Unit*	Heat Content Per Fuel Unit (Btu)	Fuel Price Per Million Btu	Heating Appliance	Type of Efficiency Rating	Efficiency Rating or Estimate	Approx. Efficiency	Fuel Cost Per Million Btu
Fuel oil (#2)	Gal.	$2.360	138,690	$17.02	Furnace or boiler	AFUE	78.0	78%	$21.82
Electricity	kWh	0.116	3,412	34.00	Furnace or boiler	Estimate	98.0	98%	34.69
					Air-source heat pump	HSPF	7.7	226%	15.06
					Ground-source heat pump	COP	3.3	330%	10.30
					Baseboard/room heater	Estimate	100.0	100%	34.00
Natural gas	Therm	1.230	100,000	12.30	Furnace or boiler	AFUE	78.0	78%	15.77
					Room heater (vented)	AFUE	65.0	65%	18.92
					Room heater (unvented)	Estimate	100.0	100%	12.30

Courtesy of the U.S. Energy Information Administration; * U.S. average

Open-loop systems tend to be more complicated than closed loops. One perception about open-loop systems is that they increase the temperature of the water source, affecting plant and animal life. This usually isn't an issue because of the minimal differences in temperature and the size of the water body. A bigger concern is the plants and animals themselves—open-loop systems often have maintenance issues with biologic and particulate infiltration. Open-loop systems are more regulated and often require extensive permitting.

The digging and drilling process depends on the type of system installed. Many closed-loop systems only disturb an 8- to 10-foot-square parcel of land. Other types of systems vary in the amount of disturbed yard. With the exception of extremely sandy soil conditions (poor heat conductivity), the type of soil is not a consideration for the effectiveness of a system. However, some soil types (such as extremely rocky) can affect the drilling process.

How It Compares

When deciding on space and water heating systems, homeowners must weigh the cost and energy usage. The actual savings from switching to a GSHP depends on the type of fuel previously used, the location, the weather, and the price of electricity.

Compared to conventional heating-oil systems, GSHPs can cut fuel costs by 50 to 80%. Heating oil is most common in the Northeast—the U.S. Energy Information Agency (EIA) states that of the 8.1 million households that use heating

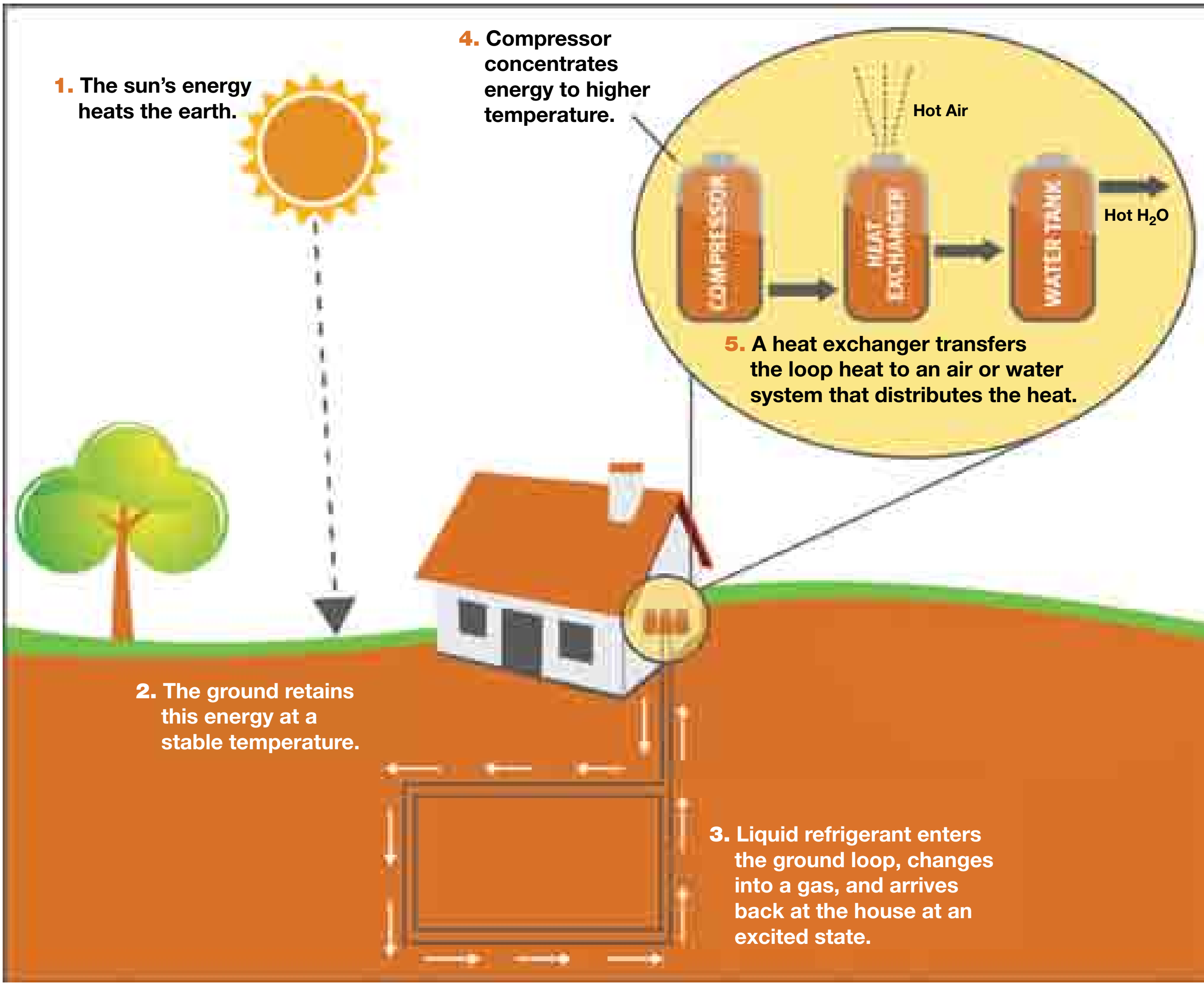
The ground loop, exiting the basement and entering the ground. Notice the snow—ground-source heat pump systems can be installed in almost any climate.

Courtesy Terraclime Geothermal

Sizing a System

The capacity of a heat pump system is measured in tons (1 ton of heat is 12,000 Btu/hr. or 3.5 kilowatts). A GSHP system costs $5,000 to $12,000 a ton, depending upon conditions of the home, especially ducting requirements. Insulation and weatherization are especially important considerations. If your home is poorly insulated, and has leaky windows and doors, improve those before getting an estimate for a new energy system. Most efficiency measures will be cheaper than the cost of a GSHP sized to make up for the inefficiencies.

With a return on investment of approximately three to five years, the Priors have gained independence from volatile oil prices and have a reliable system that will provide heating, cooling, and hot water for years to come.



Courtesy Terraclime Geothermal

oil, roughly 78% are in the Northeast. Besides being a non-renewable fuel, heating oil emissions are linked to poor air quality and resulting health issues, according to an Environmental Defense Fund study.

Heating oil systems make heat pumps a very attractive alternative, but how do they compare to cleaner, cheaper natural gas? Slightly more than half of the homes in the United States use natural gas as their heating fuel. When compared to electricity, the prices of both fuel oil and natural gas are more volatile, so knowing annual averages can help predict an accurate payback to see if the investment is worthwhile financially.

Heat pumps run on electricity only and can increase electric bills when switching from fossil fuel. The Priors' electric bill increased by almost $50 on average per month (see "Making the Switch" sidebar). During the heating/cooling seasons when the GSHP is working the most, the typical draw is 1,000 to 5,000 watts for a 1.5- to 6-ton system. Systems are usually designed for a 50% duty cycle.

In-ground view of a copper tubing ground loop.

Courtesy Terraclime Geothermal

Courtesy Terraclime Geothermal (3)

The inner components of a ground-source heat pump.

Inside the air handler (aka "air coil"), which is analogous to a car's cooling radiator coil.

An air handler for a GSHP can be added to an existing central heating system.

Heat pump systems are easily mixed with other energy solutions (hybrid systems). Heat pump and solar hot water systems complement each other. The GSHP can augment water heating, while also heating or cooling the home. Alternatively, one could route the solar-heated hot water from the roof to the ground loop to increase the thermal conductivity factor (aka, k-factor) of the looped system.

GSHPs compare favorably to traditional heating systems, especially in terms of system durability and longevity, and maintenance. A typical heat pump system lasts about 25 years and requires minimal maintenance. "All I have to do is change the air filters every six months," says Gary Prior, "much less work than writing a check to the oil company each month."

System Economics

Given volatile oil prices and an inefficient 30-year-old furnace, the Priors recognized a GSHP as an opportunity to save energy and gain freedom from oil prices. During the final winter the Priors bought fuel oil, oil prices topped $3.85 a gallon—the year that saw the largest single-year spike in oil prices. The relatively stable energy costs of a GSHP offered the Priors, who are near retirement age, some economic peace of mind.

web extra

Use the EIA Excel spreadsheet to compute your own energy and cost savings. Download it at www.eia.doe.gov/neic/experts/heatcalc.xls

Distributing the Energy

How the heat and cooling energy of a GSHP system is distributed is important to the system's efficiency. There are two main methods of distribution:

- **Hydronic radiant floor heat** is the most efficient distribution method. This strategy routes a heated fluid (water or a glycol solution) through pipes under or in the flooring. Objects near the floor are warmed first with minimal heat lost toward the ceiling. This option is more expensive than the others, and is limited to heating.
- **Hydronic radiators** work similarly to radiant flooring, and do not usually require the high temperatures (180°F or higher) of baseboard and steam radiators.
- **Forced-air** systems, which use a blower to push air through ducts and vents, are fairly common distribution method. This can be used for both heating and cooling. A second method of ducting uses high-velocity air flowing through small, flexible tubing about 2 inches in diameter instead of normal 6-inch ducting. Instead of being in the walls, high-velocity ducting is attached to the wall. This distribution method is a great option for historic homes and homes with solid walls (such as log cabins) where ducting cannot be installed in the walls. However, high-velocity systems tend to be noisier and must be maintained to prevent leaking air, which can cause noise.

Courtesy Terraclime Geothermal

Two (of four) hot water exchangers and a water storage tank make up this hydronic heating system.

In addition to saving money on their bills, the Priors benefited from both federal and state incentive programs, which offset their initial investment of approximately $29,000. For 2008, when the system was completed, the Priors received the maximum federal tax credit of $2,000—the cap for the 30% credit. As of January 2009, the cap has been eliminated, so homes like the Prior's could now receive the entire 30% federal tax credit.

The utility-based Connecticut Energy Efficiency Fund rebated $500 per ton, or $1,500, for the Prior's system. Since then, the Connecticut Clean Energy Fund added an American Recovery and Reinvestment Act of 2009 rebate that awards qualified Connecticut homeowners $2,000 per ton for retrofit projects, up to $12,000.

A GSHP system's financial benefit hinges primarily on the relative costs of electricity and fuels, which vary depending on the time of year and region. These systems typically have lower operational costs than most. Homeowners may save 20 to 60% annually on utilities by using a GSHP. Check with your local government and utility for incentives and grants to offset the initial system's cost.

Access

Samuel E. Johnston (sjohnston@terraclimegeo.com) has more than 30 years of experience in data acquisition and control, and energy management systems, including GSHPs. He works for Terraclime Geothermal, determining the marketability of ground-source heat pumps. He performs energy analyses to assess, design, and optimize the performance of energy systems.

Off-Grid Batteries

30 Years of Lessons Learned

by Allan Sindelar

Thirty years ago, an off-grid PV system was likely to consist of a couple of solar-electric modules and a pair of automotive or truck starting batteries. The system had no inverter, as reliability was still nearly a decade away, and the 12-volt system was likely to power little more than a few DC car-type tailights, a car stereo, and maybe a few RV appliances.

In those days without adequate how-to information, off-gridders were likely to use car batteries. The PV modules charged the batteries, but not being the right "tool" for the job, they often failed to hold their charge after only a year or two.

Home Power published its first issue in 1987, primarily to spread how-to and homebrew information for early solar pioneers. In the premier issue, *Home Power* founder Richard Perez writes, "After many battery failures and much time in the dark, we finally tried a real deep-cycle battery. These batteries were hard to find; we had to have them shipped in, as they were not available locally. In fact, the local battery shops didn't seem to know they existed."

The first deep-cycle batteries were not developed for remote home systems, but were adapted from other uses—golf carts, supermarket floor scrubbers, and mining cars. A few pioneers could afford to order industrial-grade "traction batteries" directly from battery manufacturers. Some off-grid pioneers reused batteries that were routinely replaced by railroads and telephone companies long before their life was up; these were once commonly available for a fraction of a new battery's cost.

Our understanding of what works and lasts has improved considerably. Some of this information remains unchanged over the decades and some is newly emerging. This article will focus on batteries in off-grid residential applications, and their selection and sizing.

Selection

For off-grid applications, flooded lead-acid batteries are the most common, although sealed batteries are sometimes used (see "Basic Battery Concepts" sidebar).

Golf-cart batteries are mass-produced by the millions. Even with price increases in recent years, they remain the best low-cost choice for small systems. Seldom does a set last more than seven years; typically they last 4 to 5 years. However, they will stand up to remarkable abuse, including chronic undercharging and lack of equalization, still providing adequate service. For some systems, frequent replacement of a set is a reasonable, low-cost approach, and their size and weight (62 lbs., about the same as a large car battery) make them easy for a homeowner to handle.

Allan Sindelar

A classic golf-cart battery: 6 V, 225 Ah at a 20-hour rate; 10 3/8 in. wide by 7 1/8 in. deep x 10 7/8 in. tall; 62 pounds.

At 225 Ah at 6 V, a 24 V set of four provides about 4 kWh of usable energy, so these batteries are only for small systems. Given their short life expectancy, I have seen the three-string limit (see "string sizing section") exceeded without the shorter-life penalties of more expensive batteries, but even four strings yields only about 16 kWh. At 48 V, two strings offer the same kWh capacity; designing a relatively small off-grid system at high nominal voltage could be a good approach.

L16 batteries and similar "commercial" batteries were originally designed for use in supermarket floor scrubbers, where they were run all night and charged from the grid the next day. Their combination of size, deep-cycle performance, and relatively low cost makes them an acceptable choice for

some RE systems. With three cells (6 V) and 350 to 400 Ah, these batteries are well-suited for small-to-medium systems. However, they are more expensive per Ah than golf-cart batteries without supplying substantially more cycle life; 5 to 8 years is typical. At 120 pounds, they can be moved by two people fairly easily.

Several manufacturers are now offering 2 V batteries using the same overall case dimensions as the 6 V models. Using a lower-voltage, higher-capacity battery means fewer strings in parallel for the same kWh storage (see "Battery String Sizing" section). Some are simply three cells connected internally in parallel rather than series; others are true 2 V cells with thicker plates and a longer cycle life.

Industrial batteries are available in a wide variety of configurations, up to about 2,500 Ah per cell. Industrial batteries no longer fit a dimensional standard, as they are not adapted from another industry. Rather, the number and size of lead plates determines both the capacity and physical size of each cell. A battery bank is sized to the desired capacity, and cells ordered in cases holding one, two, three, or six cells. Some cells can be removed from the cases for ease of installation, others use welded interconnects between adjacent cells. Installation must be carefully planned to manage a weight that can easily exceed 300 pounds.

A typical L-16-type battery: 6 V, 370 Ah at a 20-hour rate; 11 3/4 in. wide by 7 in. deep x 16 1/2 in. tall; 113 pounds.

Courtesy Deka Solar

Allan Sindelar

Twelve 2 V IBE batteries in individual steel cases, wired as a single string for 24 V.

Industrial cells are substantially more expensive: $2,000 to $10,000 for a set is not uncommon, depending on capacity. Their substantially greater cycle life—15 to 20 years of good performance is typical—has been shown to be the best bargain on a lifetime basis. This is especially so if replacement labor is amortized into the life-cycle cost, as they are replaced less frequently. Some long-time installers will only sell industrial cells, preferring to maintain a positive relationship with their customers over the long haul.

With newcomers to off-grid living, however, installers may advise a set of L16s or even golf-cart batteries as a training set, rather than suggesting more expensive batteries. Some homeowners are simply better than others at maintenance duties, and a ruined bank of industrial cells is a bitter pill to swallow. An inexpensive first set is a smaller investment, and allows for several years of adjustment to an off-grid lifestyle and load-watching. Plus, because of change in family size and lifestyle, the replacement industrial bank may end up larger or smaller than the load analysis determined in the initial design.

Sealed batteries offer some benefits over flooded batteries. They require no maintenance beyond proper charging. As the

Warranties

The warranties on batteries vary tremendously by brand and battery type. At the most basic, warranties may be for a year or two; some of the best written warranties are for as much as 10 years. Warranties will usually include a free replacement period, followed by a prorated term during which a replacement will be supplied at a reduced price. The key to warranties, however, is that they are designed to cover manufacturing defects, not perceived overall premature failure due to poor maintenance and loss of capacity from sulfation. That is, if a single cell fails during the warranty period, the cell (or battery case with that cell) may be replaced under warranty. However, if the entire bank fails prematurely, it won't be covered.

Basic Battery Concepts

Cell: The basic building block of any battery is the cell, the unit in which the chemical reactions of charging and discharging occur. All lead-acid cells nominally produce 2 V; a 12 V battery has six cells connected in series.

Battery: A battery is a generic term for a collection of one or more cells in a single case. This can be confusing, as we are used to thinking of a car battery (12 V with six cells) or a golf-cart battery (6 V with three cells, but as large and heavy as a large car battery). In most PV applications, batteries have one to six cells. The cells may be of any size, but the term remains the same. In fact, the larger the capacity of each cell, the fewer the cells in the battery case.

Flooded: The most common batteries in off-grid residential systems are flooded lead-acid. Flooded refers to an internal structure that uses a liquid sulfuric acid and water electrolyte to submerge suspended lead plates.

Sealed: Sealed batteries, better known as valve-regulated lead-acid (VRLA) batteries, surround the lead plates with an electrolyte that is either gelled (gel batteries) or absorbed within a fiberglass mat (absorbed glass mat or AGM batteries). Opinions vary in the industry as to which sealed type performs better in off-grid use.

Shallow: A car battery is the perfect example of a shallow-cycle battery. It has to supply high current to start a stiff engine in below-zero weather, so it has multiple thin plates to maximize surface area for more starting current. This is why automotive batteries are rated in "cold-cranking amps." Even a cold start, however, only discharges a few percent of the battery's capacity; it then is immediately recharged by the car's alternator.

Deep: A deep-cycle battery has fewer but much heavier plates, as it is designed to be deeply discharged and recharged multiple times without damage. Deep-cycle batteries are rated in amp-hours (Ah), a measure of the battery's ability to deliver current over an extended time.

Series: A series connection adds voltage by connecting individual cells positive-to-negative. Six 2 V cells in a battery are connected in series to make 12 V. Either four 6 V batteries or twelve 2 V batteries connected in series makes a 24 V battery string.

Parallel: Parallel connects strings of the same voltage together, positive-to-positive and negative-to-negative, to increase the battery bank's capacity. For example, wiring two 12 V, 220 Ah batteries in parallel will make a 12 V, 440 Ah bank.

Bank: Multiple batteries connected together, in series and/or parallel, are referred to as a "bank" instead of individual batteries.

Amp-Hour: Any cell or battery has a specified capacity, described as the amp-hour capacity (Ah) of the battery. This is a common term for comparing types and sizes of batteries.

Kilowatt-Hour: A more useful term is the kilowatt-hour capacity (kWh) of a battery bank: this is the amp-hour capacity multiplied by the bank's nominal voltage.

State of Charge (SOC) and Depth of Discharge (DOD): These are the terms for how charged or discharged a cell or battery is, usually expressed in percent. The two always add up to 100%: a cell that has a 70% SOC has a 30% DOD.

Days of Autonomy: An off-grid RE system is sized so that the total amount of daily charging energy from all sources—PV, wind, hydro or generator—exceeds the home's total average daily load. The major role of the battery bank is to store energy between charging periods. Days of autonomy refers to the theoretical number of days that a battery could supply the total average daily load without recharging, usually down to a minimum threshold of about 80% DOD (20% SOC).

C/Rate: This ratio is used to quantify charge and discharge rates. It refers to the rated capacity of a cell or battery divided by the number of hours to either fully discharge or charge it. For example, a common golf cart battery has a capacity of 220 Ah. If a 22 A load is placed on the battery, it is being discharged at a C/10 rate (220 ÷ 22 = 10). If the battery is then recharged by a PV array producing 11A, it's being charged at a C/20 rate. A 1,000 Ah battery would need to be charged at 50 A to achieve the same C/20 rate.

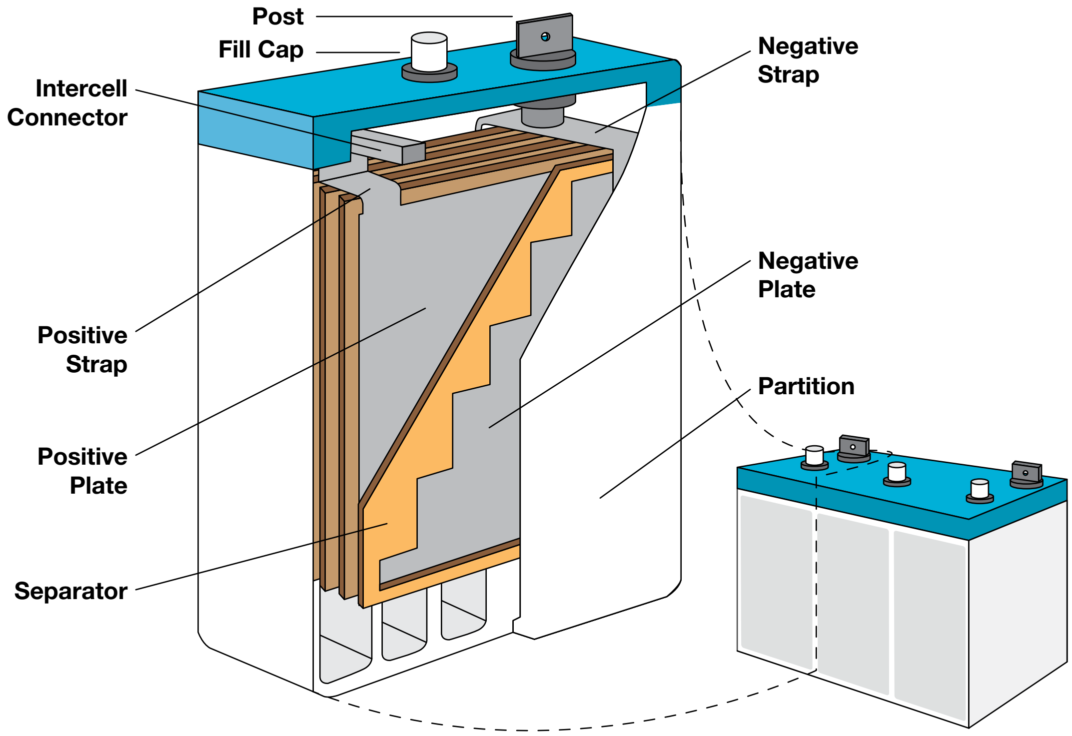
Allan Sindelar

Concorde PVX-4050HT sealed AGM in an L-16 format; 6 V, 400 Ah at a 20-hour rate.

electrolyte is either gelled or absorbed, they don't gas during normal charging. Lacking liquid electrolyte, they are charged to lower voltages and can tolerate small arrays and lower charge rates, as long as they regularly reach and maintain full charge. They don't require adding water or equalizing, plus they don't leak and won't foul battery storage areas or attract corrosion on terminals. Absorbed glass mat (AGM) batteries are non-spillable and non-hazardous, so can be shipped via common ground and air freight with no hazardous material costs. Since access to the cell tops to add water is not necessary, they can be mounted in any orientation without harm. Their stackability means they may occupy less floor space than flooded batteries.

But sealed batteries are not without their drawbacks. AGM batteries may last longer than inexpensive flooded batteries, but not as long as industrial flooded batteries. For example, Concorde estimates seven to 10 years of service in

Anatomy of a Flooded Lead-Acid Cell



off-grid use. They are substantially more expensive: typically double the cost of industrial cells of similar capacity. They are more susceptible to damage from overcharging.

These batteries are well-suited to homeowners who don't want to perform their own battery maintenance. This includes many newcomers to off-grid living, who want (and can afford) a professionally designed and installed system, and can live well within its limitations, but prefer not to be involved with battery maintenance. Sealed batteries are also well-suited to cabins and homes with seasonal use and little maintenance, and for weekend cabins in which small arrays and larger banks provide energy for weekend use.

PV-to-Battery Sizing

Originally, deep cycle batteries were meant to be cycled during a work shift and then be immediately and fully charged daily with utility power: a predictable and well-managed charging regimen. In an off-grid home system, both loads and RE resources vary from day to day and season to season. Some days, batteries will be full by mid-morning; at other times, batteries may not be full for days. Opportunity charging is the term given to the treatment of batteries in RE systems: the charging system takes maximum advantage of any RE source when it's available. In practical terms, this means that charge voltage settings are often set higher, and absorption times are often set to the maximum available—often 4 hours (with the 2% current threshold as an override, to minimize daily gassing when a system is left unused)—see "The Charging Process" sidebar on page 87.

To accomplish proper charging of flooded cells, the charge rate has to be high enough to overcome the cells' internal resistance. A PV charge rate of C/20 or better is generally considered the minimum needed. For a 1,000 Ah battery at 24 V, this would be 50 A (plus enough to meet the household loads)—or a PV array rated at more than 1,500 watts. While a C/20 rate is the minimum, the preferred rate is between C/12 and C/6, so for each 100 Ah of flooded battery capacity, the combined DC charge rate should be at least 8 A, or C/12, and

The active material on the plates is comprised of lead oxide, acid, water, and fiber. The plate grid metal is lead with 4.25% antimony. The white material is the glass matting used to assist in improving cycle life. Left: A 0.260-inch-thick positive plate from a Surrette industrial cell. Right: A smaller plate from an L-16 cell.

Allan Sindelar

Allan Sindelar (3)

A Surrette series 5000 industrial battery: 4 V, 546 Ah at a 20-hour rate.

not more than 16 A, or C/6. This is the combined amperage of all charging sources, including a PV array, wind or hydro generator, or an engine generator.

In the early years, PV modules were far more expensive than today, and batteries were less expensive. Early practice was to size for 4 to 8 days of autonomy, but that led to small arrays and large battery banks, resulting in chronically inadequate charging. Some old-timers will remember "one module per battery"—modules were 35 W to 50 W, or 6 A per pair of golf-cart batteries. At 220 Ah and 6 A of charge, this resulted in a C/36 rate: too low for good battery care.

Modern systems now call for only 2 to 3 days of autonomy, as long as the system includes a backup generator to make up for extended cloudiness. If the budget allows, array capacity is expanded, rather than increasing battery capacity.

Battery String Sizing

Fewer parallel battery strings in a bank means better performance over the batteries' life. Slight imbalances between strings within a battery bank can cause increasingly uneven performance, leading to premature failure of part of a bank and early replacement of the entire bank. Larger individual cells allow for fewer strings, as does higher nominal system voltage. A single series string is a wise choice, and two strings in parallel are considered acceptable. Three is the maximum number of parallel strings, but should be avoided if possible.

Battery-based systems are generally wired at 12 V, 24 V, or 48 V. Systems have progressively moved toward inverter-based AC loads, so 12 V system advantages have largely disappeared, and the strong disadvantages of high current and large wire sizes discourage the use of 12 V for all but RV and portable applications and the smallest cabins with minimal loads.

For a 48 V system, a single string of batteries of the proper Ah capacity is recommended. If a single cell fails, it can usually be temporarily bypassed until a replacement cell is installed, and the system can remain in use. Even with the temporary bypass of three cells (an entire battery), as would be the case with a string of eight 6 V batteries, set points can often be adjusted to allow the 48 V system to operate at 42 V.

Twenty-four volt systems are often designed with two strings, as the failure of either a cell or a 6 V battery requires only that one of two strings be temporarily disconnected from the system.

Temperature Effects

All lead-acid batteries lose their effective capacity as they get cold. The loss varies slightly for different batteries and is almost in direct proportion to their temperature. For example, at 0°F, a battery can supply about 55% of its 77°F capacity. Low-temperature capacity loss isn't permanent; raise the temperature and the capacity returns. But most off-grid systems are most stressed in winter, when days

Two paralleled 24 V strings of 6 V Deka L-16 batteries in an enclosure sized for three strings, interconnected and arranged to allow easy access to the electrolyte caps for maintenance.

A single 24 V string of 2 V flooded cells has about the same size and capacity as the three strings of L-16s, but with fewer cells to water and fewer interconnects.

The Charging Process

Early charge controllers were crude: generally little more than voltage-actuated on/off relays. Modern charge controllers have substantially improved battery charging and longevity.

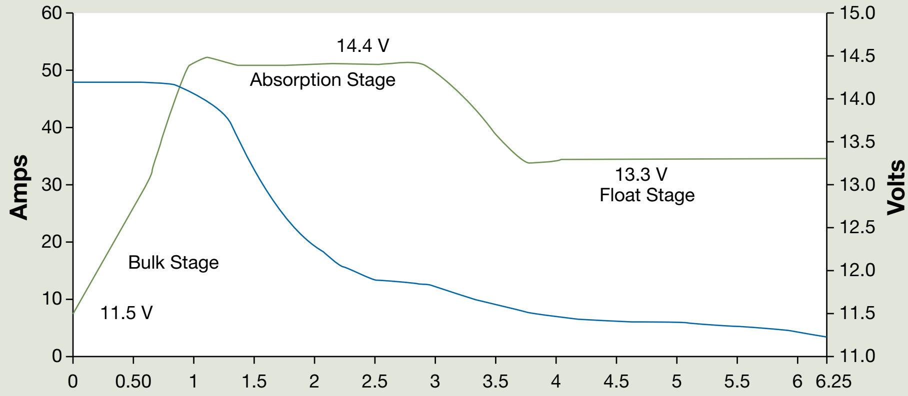
The charging process for flooded cells involves four steps: bulk, absorption, float, and equalization. During the bulk phase, which generally fills the cell to around 85% of its capacity, the charge controller (from a PV, wind, or hydro source) or the inverter (from a generator or AC source) allows all available charge current to flow into the cells. As the current is absorbed by the plates in the cell, the cells' voltage steadily increases. When the voltage reaches the bulk voltage set point (typically about 2.45 V per cell), the controller moves into the absorption stage. During absorption, the voltage is held at the bulk set point, and the charge is regulated to the current necessary to maintain that voltage (plus power any loads that are on).

When any flooded lead-acid battery approaches full-charge voltage, the cells begin to "gas." The cells are no longer able to absorb all of the energy, and the excess energy separates water in the cells into hydrogen and oxygen gases. Gassing is an important part of the charging process: the process brings weaker cells closer to the charge level of stronger cells, and the bubbling action destratifies the electrolyte.

As the cell approaches 100% SOC, the amount of current necessary to maintain this voltage steadily drops. When either a preset time duration (typically 2 to 4 hours) is reached, or the charge current drops below a set threshold (typically a C/50 rate, or about 2% of a healthy cell's capacity), the cell is considered fully charged, and the controller moves into float stage. During float, a tiny amount of current holds the cell slightly above its resting voltage, and the charging process is finished until the next charging cycle.

Equalization is the periodic, deliberate overcharge of a full battery. It stirs up the electrolyte, breaks up light sulfation (which is what eventually wears out a battery), and evens out the chemical state of charge in each cell. It generally requires taking the full cell up to about 2.6 V and holding it at or above this threshold for several hours.

Example Three-Stage Charge Curve (12 V, 221 Ah battery)



This graph is from Surrette for their 12 V, 221Ah battery. Often, manufacturers provide a range of bulk and float voltage values. While this graph displays values toward the middle of that range, PV charge controllers will usually be set to the higher end of that range.

How *not* to do it: Four parallel strings, with cables attached at one end and interconnects interfering with access to the caps for watering. Extensive acid corrosion around several terminals prevents good electrical conductivity.

Allan Sindelar

are shortest and loads are typically greatest. Adding the reduced capacity of frigid batteries only exacerbates this seasonal weakness.

Batteries thrive in a thermally tempered space, with a temperature that seldom drops below 50°F. This can often be achieved by housing them in a space that is well-insulated, has south glazing with overhangs, and adequate thermal mass (the batteries themselves contribute substantially). Batteries don't need to remain in a heated indoor space, although this too can be done safely and effectively. They do need to be protected from uneven temperatures from radiant heat sources, including exposure to

direct sunlight, as identical cells at different temperatures will not perform equally.

A second consequence of temperature's effect on battery performance is that a cold battery must be charged to a higher voltage than a warm battery to achieve the same SOC. All modern, quality charge controllers have temperature compensation to adjust the charge voltage according to the battery's temperature. In most cases, the sensor is attached to the battery terminal or case. Unless a battery's temperature remains constant, a temperature sensor is an important component of an RE system. Without temperature compensation, cells will not reach 100% SOC in winter. In summer, they can be overcharged, reducing battery life.

Battery Advances

While there are tremendous advances taking place in battery development, most are based around increasing a battery's performance and capacity per pound—that is, lightweight, high-capacity batteries for electric vehicles and portable applications of all kinds. In the RE industry, weight isn't a key factor; a more relevant figure has been energy density per dollar, and conventional flooded lead-acid batteries have filled this bill the best.

Battery choices have been slow to evolve, due to a unique quandary: their longevity. Since deep-cycle batteries can last 15 to 20 years, learning by experience what works best can take decades. Plus, there's only a handful of long-time off-grid installers who have been selecting, installing, and maintaining batteries for long enough to actually compare and learn from entire battery life cycles. In the absence of long-term data, we tend to use what has worked previously, rather than trying new and possibly expensive approaches.

A relatively new shift is the use of high-quality sealed batteries in some off-grid applications, but there isn't yet a large body of experience from which to draw conclusions and predict performance. The expectations of some old-timers are that high-quality, maintenance-free AGM batteries may last about seven to 10 years in full-time off-grid use, with good care.

Access

Allan Sindelar (allan@positiveenergysolar.com) installed his first off-grid PV system in 1988. In 1997, he founded Positive Energy of Santa Fe, New Mexico. He has lived off-grid since 1999. Allan is a licensed commercial electrician and a NABCEP-certified PV installer.

Further Reading:

"Top Ten Battery Blunders: And How To Avoid Them" by Windy Dankoff in *HP114*

"Flooded Lead-Acid Battery Maintenance" by Richard Perez in *HP98*

"Designing a Stand-Alone PV System" by Khanti Munro in *HP136*

"Toast, Pancakes, and Waffles: Planning Wisely for Off-Grid Living" by Allan Sindelar in *HP133*

For a listing of battery manufacturers and their products, see "Choosing the Best Batteries" in *HP127*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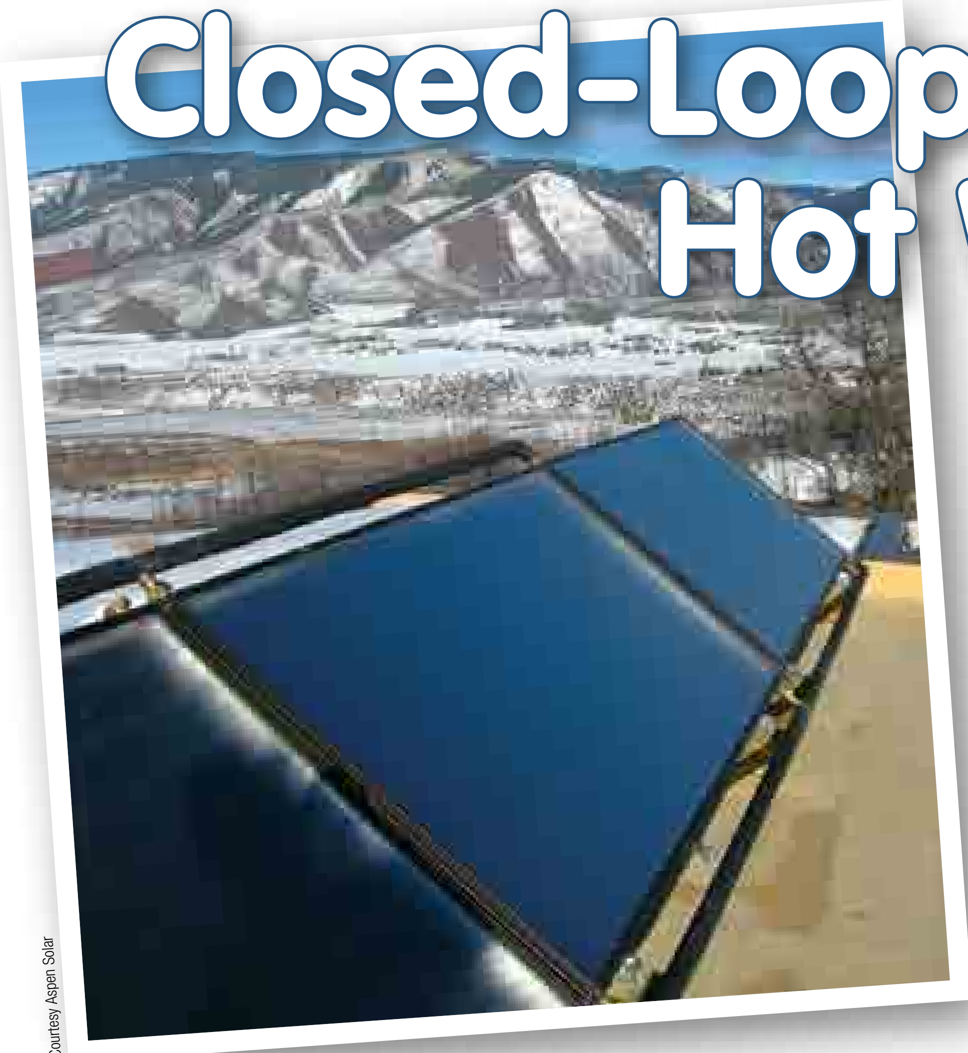
Closed-Loop Solar Hot Water

by Brian Mehalic



Courtesy Aspen Solar

In all but the most temperate climes, some form of freeze protection is important for solar hot water systems.

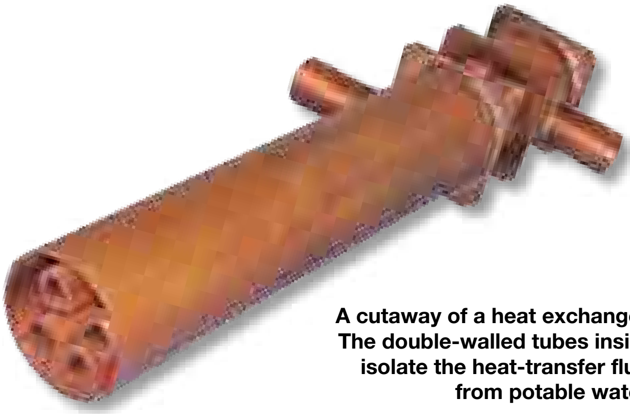
For most of North America, freeze protection for solar hot water (SHW) systems is essential. Even though a freeze may not be a regular occurrence, over the 15- to 25-year expected life of a SHW system chances are high that freezing conditions will be encountered. It only takes a single freeze to damage pipes, collectors, and other system components; and damage to the building structure can also occur from burst pipes and leaking heat transfer fluid (HTF) or water.

Using an antifreeze solution as the HTF is a common freeze-protection strategy. The chemistry of the fluid keeps it from freezing, down to a certain, known temperature, based on a given level of dilution.

Closed-loop systems are very versatile, and are commonly used for domestic and commercial water heating, for space heating, and for dual-use systems, such as in a snow melt and pool-heating combination.

Systems using antifreeze HTF have a separate plumbed "loop" that circulates through the solar collectors and transfers the heat collected to end-use water in a storage tank through a heat exchanger. This loop is pressurized, meaning that it's sealed and filled with fluid to a certain pressure at installation, and circulated by a pump operated by a differential controller. When the controller detects that the collector temperature exceeds the stored water temperature by a preset amount, the pump is activated. When the temperature difference decreases to a set amount, the pump shuts off. Whether the system is being pumped or not, the collector loop is always full of HTF.

The pressure of the HTF loop should be less than that of the domestic water. Fifteen to 25 PSI is adequate for most domestic systems. In the event of leakage occurring between the two loops, the higher-pressure domestic water would leak into the HTF, rather than the HTF contaminating the potable water. It is also important to set the HTF loop pressure so that the pressure does not get too high when the fluid is hot. There can be a difference of 20 PSI or more between unheated and hot HTF.



A cutaway of a heat exchanger. The double-walled tubes inside isolate the heat-transfer fluid from potable water.

Antifreeze as an HTF

Water can be used as the HTF—compared to other, denser fluids, it takes less energy to pump. Its specific heat is 1, meaning it takes 1 Btu to raise 1 pound of water 1°F; this is higher than other common HTFs, and means that water has a higher heat content per volume and is thus more effective at gathering heat. However, water freezes at a too-high temperature (32°F), offering little or no freeze protection. Plus, it expands as it freezes, increasing the likelihood of damaging its container—the solar collectors or the piping.

Water also boils at a relatively low temperature (212°F), though as with all fluids, when contained in a pressurized loop, the temperature at which it boils increases. This is important, especially if stagnation (meaning that the system stops pumping, even though heat is available) occurs. Stagnation can result from pump failure or if the controller deactivates the pump for "high-limit" temperature in the end-use water. (In poorly sized or underutilized SHW systems, this can be a common occurrence during hot months.) During stagnation, the collector HTF temperature can be far in excess of the boiling point of water, resulting in steam being produced, and fluid loss through pressure-relief valves. While water is an efficient HTF, its narrow operating range precludes it from use in all but the mildest climates.

Other Options

In areas where freezing is very rare, **batch systems** (aka integrated collector storage; ICS) are suitable. With ICS, a large volume of water (30+ gallons) is stored in one or more collectors, heated, and drawn out as needed.

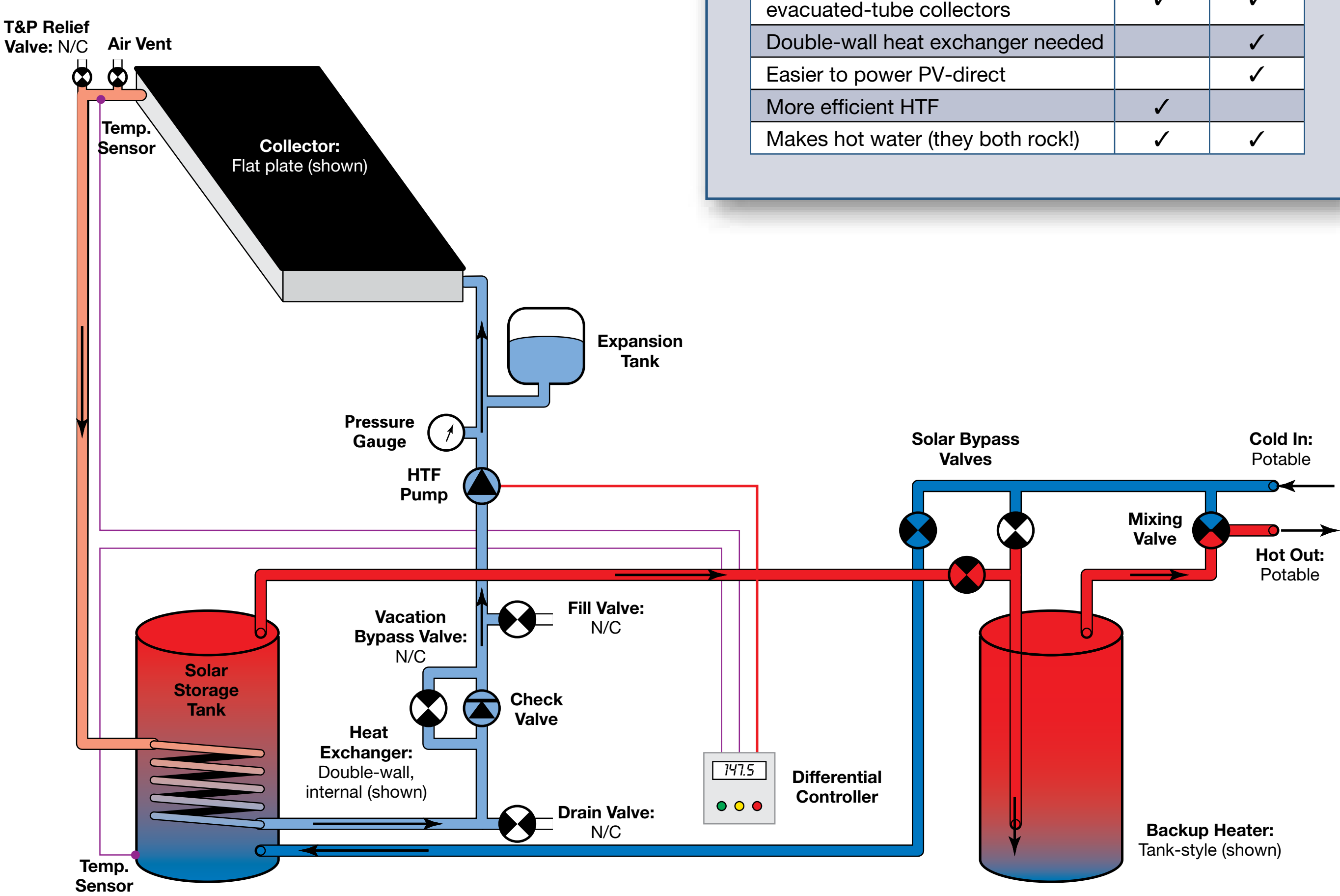
Because the end-use water is heated directly without the need for pumps, these systems can be very efficient. They require fewer components, and are common in parts of the Sun Belt states and in tropical climates. The thermal mass of the water can prevent freezing from occurring. However, in marginal areas, or locations with a greater chance of freezing, this may not be sufficient. The piping to and from the collector, which has much less mass than the collector itself, is the weak point and most likely to burst in a freeze.

Drainback systems are commonly used in freezing climates. When this type of system is not operating—i.e., not actively pumping heat transfer fluid through the collectors—the HTF drains from the collectors into a storage tank located in a conditioned space, eliminating the potential for freezing. For more information on drainback SHW, see *HP97* and *HP138*.

Closed-Loop vs. Drainback

Attribute	Drain-back	Closed-Loop
Better protection from overheating	✓	
Smaller pump required		✓
HTF lines don't have to slope		✓
Use with flat-plate or evacuated-tube collectors	✓	✓
Double-wall heat exchanger needed		✓
Easier to power PV-direct		✓
More efficient HTF	✓	
Makes hot water (they both rock!)	✓	✓

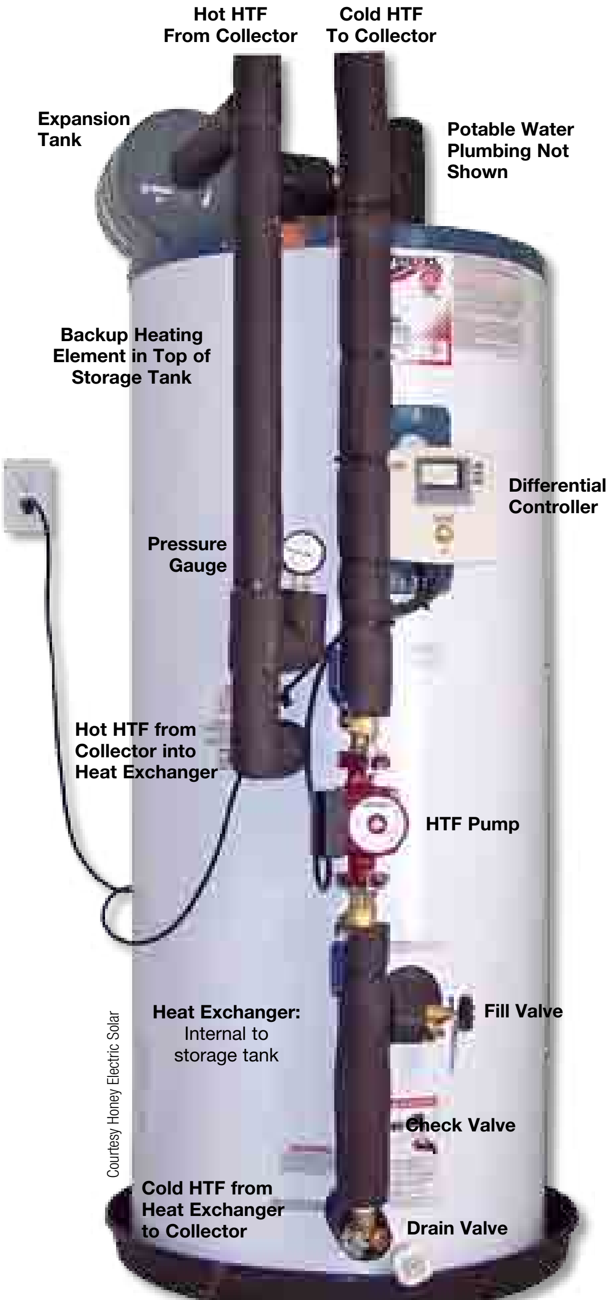
Basics of a Dual-Tank, Closed-Loop SHW System



Propylene Glycol Mixtures & HTF Properties

Attribute	Water Only	50% Glycol	100% Glycol
Specific heat at 150°F (BTU/lb./°F)	1.00	0.86	0.66
Boiling point (°F)	212	222	310
Burst protection (°F)	32	-20	-100
Specific gravity	1.000	1.041	1.036

Single Tank, Closed Loop



Using the right mix of antifreeze and water increases freeze protection, and maintains as much of water's heat transfer capability as possible. Several different chemicals have been used as antifreeze HTF in SHW systems. The most common is propylene glycol, which is used in products ranging from deodorant to toothpaste; as an emulsifier in processed foods; for de-icing airplane wings; and in many other applications. It is closely related to ethylene glycol, which is most commonly used as antifreeze in radiators for engine-cooling systems. Both are more viscous than water and typically are dyed glowing-green, but ethylene glycol is much more toxic and can be fatal if ingested. Ethylene glycol must *not* be used in SHW systems to avoid contamination of end-use water. (See "Fundamentals of Solar Heat Exchangers" in *HP128* for more information.)

Pure, or 100%, propylene glycol has a much wider range of operation than water, with a freezing point of -74°F, and a boiling point of 310°F. It is more dense and more difficult to pump than water, though this is not usually an issue in most residential closed-loop applications utilizing AC pumps. Systems with long pipe runs, and especially with multiple collectors, require careful pump selection. The HTF in many SHW systems is a mix of propylene glycol with distilled water to avoid minerals or compounds that could corrode copper piping and other components. However, depending on the mineral content of the local water supply, distilled water may be unnecessary. A 50/50 or 60/40 glycol-to-water ratio is most common. The ratio should be tailored for local temperatures (see the "Glycol Mixtures" table).

With a much lower specific heat (0.60 Btu/lb./°F), propylene glycol is less efficient at transferring heat than water. Mixing it with water increases its efficiency, so it is best to use the lowest concentration of glycol that will provide freeze protection. The downside is that greater dilution lowers the boiling point of the HTF, potentially subjecting it to high pressures, vaporization, and subsequent fluid loss in the event of stagnation.

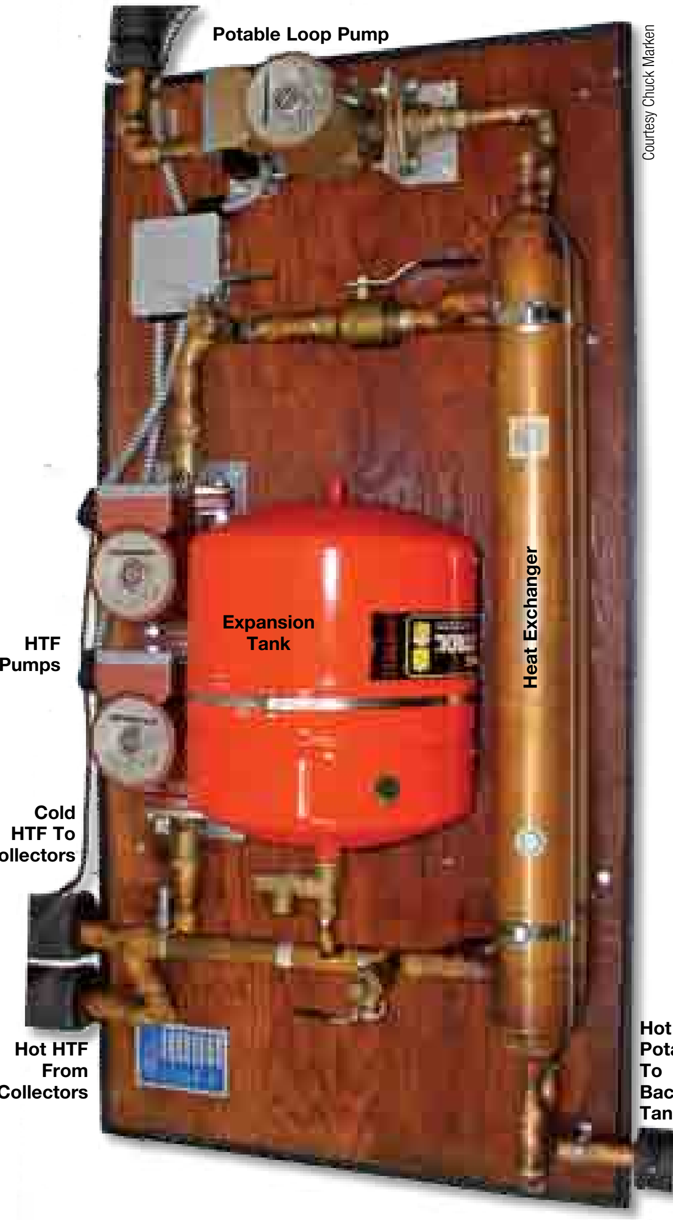
High temperatures—though they may be below the boiling point due to the pressurization of the HTF loop—also cause propylene glycol to break down. This causes acids to form, leading to corrosion. This corrosion can affect pipes, fittings, valves, seals, pump impellers, and other components, potentially causing them to fail. Particulates can start to build up in the HTF, which also can lead to clogs or further damage to the pump (see "HTF Breakdown" sidebar).

In the past, other fluids were used in place of glycol, including ethanol (Copper Cricket), bray oil (Novan), silicones, and hydrocarbons. Some HTFs may no longer be available when the system needs to be refilled/recharged. Some of these systems, such as those using bray oil, can be converted to use propylene glycol, but the HTF loop must be very thoroughly flushed with a detergent.

Left: In a single-tank, closed-loop system, a backup heater in the top of the tank augments the heat exchanger (in this case, internal) near the bottom.

Courtesy Heliodyne

Modern integrated pump stations combine controller, pumps, valves, and meters in a preassembled and insulated set.



Courtesy Chuck Marken

A SunCatcher pump and exchanger module. Manufactured in the 1980s, many of these systems are still working today.

System Components

The majority of systems that use propylene glycol as the HTF are pressurized, closed-loop systems with the following components:

Heat exchanger. Any system using propylene glycol must use a heat exchanger to move heat from the solar loop to the end-use water. Although arguments can be made against the necessity of a double-wall versus a single-wall (more efficient) heat exchanger, in most regions, local building codes specify double-wall exchangers.

Check & clean-out valves. When the collector is colder than the water in the storage tank (at night, for instance), a thermosyphon can start, removing heat from the tank by circulating the HTF loop in reverse and losing heat as radiation from the collector. A check valve allows the HTF to flow only in the correct direction to prevent thermosyphoning. A clean-out valve is also a good addition. It screens out and collects particulates in the HTF, keeping them from damaging seals and components.

Expansion tank. The HTF loop needs a glycol-rated expansion tank—a metal tank with an air bladder inside. When the HTF expands as temperature increases, the air bladder absorbs the pressure, preventing the pressure-relief valve from opening and HTF from being lost.

In addition to the expansion tank on the HTF loop, many local codes also require an expansion tank on the end-use water side of the system.

Pressure-relief valve & air vent. A pressure-relief valve opens when the pressure exceeds its rated amount, often 50 to 75 PSI. When it activates, some fluid is lost, and the system pressure drops slightly. Repeated blow-offs through the pressure-relief valve are an indication of a poorly designed or installed system, as this should not be the normal operating condition. Likely the system will suffer additional problems—such as poor performance and pump failure—as more and more system pressure is lost. The 2009 Uniform Solar Energy Code stipulates that any system using a single-wall heat exchanger shall have a pressure-relief valve of 30 PSI or less.

An air vent is placed at the highest point of the system plumbing—typically at the output of the collector—and can be used to vent air that builds up or was never initially purged from the system.

Courtesy Chuck Marken

A pressure-relief valve and air vent are commonly positioned at the highest, and hottest, point in the system—the collector outlet.

Differential controller. The controller uses thermistors, whose resistance varies with temperature, to determine the temperature of the storage tank and the collector. The controller then turns the pump(s) on and off as needed. Other features may include vacation mode (see below); the ability to change the off/on temperature differential set points; and a display showing temperatures at different points in the system.

Pressure & temperature gauges. A pressure gauge is needed to monitor system pressure and will indicate if HTF has been lost due through the pressure-relief valve or a leak in the HTF plumbing. Typically installed on either side of the heat exchanger, temperature gauges show HTF temperature as it returns from the collector and after it transfers its heat to the end-use water. This temperature drop indicates that the system is operating and shows how effectively heat is being transferred. Some controllers can provide this information, particularly temperature data.

A differential controller is the brain of the system, engaging the pump when there is a thermal resource available and disengaging when the tank is hot, or the collectors are too cool.

Courtesy Steca Solar

Circulator pump(s). Closed, pressurized loops have much less resistance (head) to overcome than drainback systems because the HTF fills the entire loop and doesn't have to be lifted from a resting point as it does in a drainback system. This allows lower-power pumps to be used. A typical residential system pump will use less than 90 watts. In some cases DC pumps that are powered directly by a PV module can be used, eliminating the need for AC power and the differential controller.

The closed loop does not require more expensive stainless steel or brass pumps because the pumps are not subjected to the corrosive effects of air and fresh water being introduced into the system. Most are made of cast iron and steel. Pumps should be plumbed so that they are accessible for maintenance—installing isolation valves on either side makes pump changing easier.

Piping and insulation. Piping must be suitable for use with glycol and the temperatures encountered in SHW systems—usually copper is used. Cross-linked polyethylene (PEX) has too low of a temperature rating. Pipes must also be appropriately sized—too small and flow may be inadequate, reducing the system's efficiency. Copper and stainless steel tubing are available in rolls, and even preinsulated with an embedded sensor wire, saving installation time. Sizes are 1/2-inch or larger depending on the number of collectors.

Components may be plumbed together ahead of time, on site, or some combination thereof. There are many manufacturers of prebuilt pump stations, with all of the necessary components for a closed-loop, pressurized system already plumbed. Installation can be as simple as mounting the unit and connecting the lines to and from the solar collectors and the tank (see "Solar Hot Water Pump Stations" in *HP134*).

Avoiding Overheating

Proper sizing is the first step toward an effective SHW system (see "Sizing Solar Hot Water Systems" in *HP118* for details). If not properly sized—either in terms of demand or in the ratio of collector to storage space—the system can be ineffective or overheat. Collector angle is also important. It is common to see collectors flush-mounted on roofs with a 3:12 to 5:12 pitch (less than a 25° tilt). In most locations, this will result in increased summer production, when the sun is high in the sky, and reduced winter production, when the sun is at a lower angle. It also increases the likelihood of summer overheating. A steeper tilt angle will improve winter performance and help mitigate summertime overheating.

Systems that are designed for meeting winter loads are typically large, using multiple collectors to produce enough heat during shorter days with less solar energy. When there is

A Grundfos 15-42 medium-head cast iron pump suitable for most small- and medium-sized antifreeze SHW systems.

less demand for hot water, such as in the summer, the systems can overheat. Drainback systems are often preferable when overheating is a factor.

Some systems use temporary covers on some of the collectors to reduce overheating. For space heating or snow-melting systems, another option is to drain the HTF from the system during the time of year when it is not needed. These strategies require effort twice a year to cover/uncover the collectors or drain/recharge the loop. The added cost and time, along with the potential for forgetting to do it, make these strategies problematic.

Another option is to incorporate some sort of heat dump like piping in the ground to transfer heat to the earth, preventing the system from stagnating. Or a second, off-season load can be added—a heating or snow-melt system may double as a pool-heating system in the summer. Note that more complex controls and plumbing will be required for these strategies; the more automated they are, the more effective they'll be.

Vacation Mode

Another overheating potential, especially for residential SHW systems, occurs during periods when the system isn't being used. Unoccupied homes (such as during vacation) with the corresponding drop in hot water use can easily lead to overheating, as the system hits higher and higher temperatures each day.

One strategy is a vacation bypass valve—a loop in the plumbing around the check valve. Normally, the ball valve in this bypass loop is closed, with flow through the check valve. Opening the ball valve allows a thermosyphon loop to bypass the check valve, and can result in the tank cooling, helping the system to avoid stagnation. But this strategy relies on the user, since bypassing the check valve requires manually opening the valve, and then reclosing it to resume normal operation. If accidentally left open, system performance can suffer dramatically.

This method also requires that a thermosyphon loop can occur, which is not always the case—it depends on the pipe run's length, height, and diameter. Thermosyphoning also does not work with evacuated tube or heat pipe type collectors, because the vacuum prevents night radiation of the heat. If an external heat exchanger is used, additional plumbing may be required to ensure that both sides—the HTF loop and the end-use water—are thermosyphoning.

HTF Breakdown

In a well-designed system that doesn't suffer much overheating, the propylene glycol HTF may last for 15 years or more. However, if a system is poorly designed, has component failures, or is underused, it is likely to overheat more often. Over time, propylene glycol that is overheated breaks down and becomes acidic. Old, "burned" glycol has a dark, almost coffee-like appearance and a foul odor, and will need to be changed more often.

Glycol breakdown is primarily due to inhibitors added to reduce the corrosion. Because different manufacturers use different inhibitors, the initial pH will vary. Check the manufacturer's product data sheet for this information. When diluted to a 50:50 mix, the initial pH will typically be between 8.5 and 9.0.

Test the pH of propylene glycol each year to determine if the HTF needs to be changed. Testing kits are available from suppliers of propylene glycol, solar equipment distributors, and other sources such as chemical suppliers. As the pH falls to 8 or less, the likelihood of corrosion increases. A pH below 7 indicates that the HTF has degraded and corrosion is likely already occurring—the old HTF should be drained, the loop thoroughly flushed with water or a detergent, and fresh propylene glycol solution added.

Disposal methods for propylene glycol vary by region. Flushing used antifreeze down the drain is the least-preferred disposal option, but it may be the only option available in some areas. Your wastewater treatment facility should be contacted to ensure that they can accept the waste. Some recycling facilities accept used glycol solutions, both propylene and ethylene glycol used in cars.

Filling and pressurizing a closed-loop system with fresh antifreeze, using the drain and fill valves and an external pump.

A vacation bypass valve creates a path around the check valve, allowing a reverse thermosyphon at night to cool the system.

A better strategy, and one available on several differential controllers, is "vacation mode," which runs the pump at night if the storage water exceeds a preset temperature. This cools the system and prevents stagnation. Depending on the controller, the vacation setting may be able to be left on. Use caution if this is the case, as an improper (too low) setting can lead to poor system performance. Other controllers have to be put into vacation mode manually, again putting the responsibility on the end user. As is the case with a bypass valve, this strategy will not work with evacuated-tube collectors.

Access

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Cheaper, Efficient Cooling with Whole-House Fans

by Neil Smith

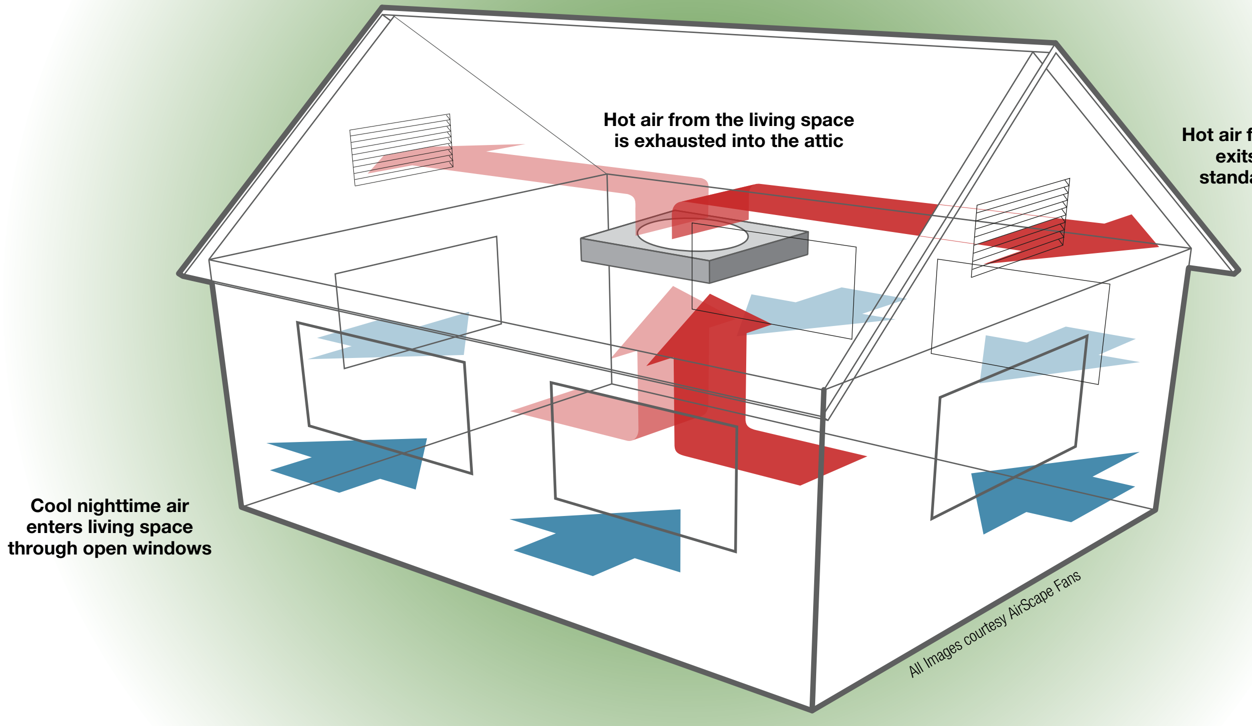
Whole-house fans, sometimes improperly referred to as "attic fans," are a class of fan that exhaust air from a house, drawing in fresh air through open doors and windows. Whole-house fans are used to cool a house when the outside air temperature is lower than inside (see figure below), and are a convenient and innocuous way to provide inexpensive cooling.

Cooling Off

Whole-house fans have been in use in the United States for much of the last century, although their mass appeal has been eroded by the availability of air-conditioning and inexpensive electricity. But as electricity rates rise and homeowners are realizing the necessity of ventilation (as well as the negative environmental impact of running central air-conditioners), whole-house fans are undergoing a renaissance.

There are several different strategies for using whole-house fans. For houses with existing air-conditioning, the most basic strategy is to use whole-house fans to eliminate air-conditioning use at night. On average, a whole-house fan uses 90% less energy than an air-conditioning unit. The only lifestyle change required is to turn off the air-conditioning, switch on the fan, and open windows on cool nights. A whole-house fan that has enough airflow to maintain cool sleeping conditions "most of the time" would be selected, which translates to a minimum airflow per bedroom of 500 to 700 cubic feet per minute (CFM), depending upon local climate. These figures for airflow are based upon user feedback. There are many factors that affect human comfort, from temperature and humidity to individual sensitivity. With enough airflow (think: motorcycle riding), one can be cooled in almost any temperature. However, at some point, the energy to pull all that air with a whole-house fan will be more than using air-conditioning.

Operation of an Attic-Mounted Whole-House Fan



An attic-mounted whole-house fan pulls hot air into the attic space (where it exits through vents) while drawing cooler nighttime air into the living-space through open windows.

Natural or "free cooling" is based upon how much cooler the outside air is than inside air. Your climate and personal comfort will help determine if you can use a larger whole-house fan to extend the time when air-conditioning is not required. This is a function of climate and personal comfort. As whole-house fans become available that have good power unloading (reduced energy use at low speeds), this upsizing becomes more practical. Whole-house fans that use 700 watts at full speed and 100 W at half speed are one of the benefits that are available with electronically commutated motors.

Another strategy is to increase the airflow to pre-cool the building. This involves running a whole-house fan all night, bringing in cool air so that the building is as cool as possible the next morning. A pre-cooled structure will stay cool longer the following day, saving additional air-conditioning use and providing comfortable conditions later into the day. For homes with sufficient thermal mass, the entire house can be pre-cooled sufficiently to eliminate air-conditioning.

Airflow

Airflow is typically measured by cubic feet per minute (CFM)—a cube of air 1 by 1 by 1 foot flowing by every minute equals 1 CFM. That cubic foot of air weighs about 1.2 ounces. At higher elevations, air becomes less dense (for instance, Denver air—neglecting particulate pollution—weighs about 0.99 ounces). Since fans blow air by volume (irrespective of air density), a 1,000 CFM fan placed in Denver will still blow 1,000 CFM. The problem is that 16% less air mass is being moved, and the mass is what does the work of heat transfer.

A common misconception concerning whole-house fan use is that it can cool down the house in 15 minutes and then you can "turn off the helicopter." But "quick cooling" a house with a blast of outside air defies the physics of heat flow. The weight of air in a 2,000-square-foot house is approximately 1,200 pounds, with an aggregate thermal capacity of 288 Btu per pound per degree Fahrenheit. According to demolition studies, a typical 2,000-square-foot house will weigh in at 222,000 pounds. Based upon the typical material mix, the weighted average specific heat of that house is 0.39 Btu/lb°F, which means that it would take 85,000 Btu (0.39 x 222,000) to raise or lower the temperature of the whole house by 1°F. Of course, the house doesn't heat up and cool down uniformly, which is one of the reasons why nothing in building heat transfer is simple. Since air is relatively easily cooled and heated, the goal must be to cool the high mass of the house. The physics of heat transfer prevents this from happening quickly.

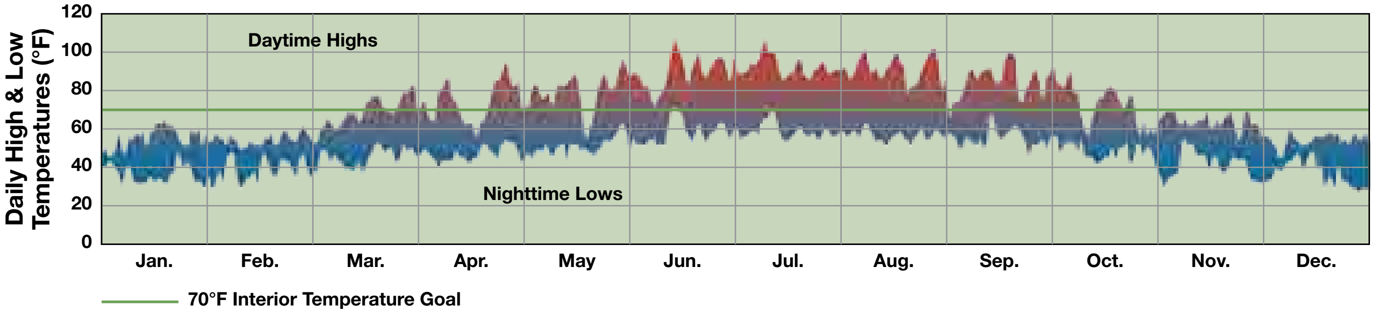
Although some houses are situated to capture breezes, most houses do not "self-ventilate," necessitating some form of mechanical ventilation. Fresh air requirements are often in the range of 0.35 air changes per hour (ACH) or 20 cubic feet per minute (CFM) per person. To put this in perspective, a 1,700 CFM whole-house fan would yield more than 6 ACH when placed in a 2,000-square-foot house with 8-foot ceilings [(1,700 x 60 ÷ (2,000 x 8)].

Older criteria simply recommended an airflow of 3 CFM per square foot. But this overly simple formula comes from a time when houses were not well-insulated—and whole-house fans were the only form of cooling available. Since natural cooling depends upon Mother Nature, technical factors, and personal preferences, it's not possible to have a definitive size for a particular case. However, customer feedback combined with engineering knowledge has resulted in developing empirical formulas for airflow that take into account cooling strategies, location, and house construction.

A rare, but promising application of whole-house fans is to incorporate ground-source cooling. If you have a basement that stays cool all summer, you effectively have the basis for a ground-source cooling system. A low-cost way to take advantage of this cooling is to open one or more basement windows, and run a whole-house fan during the day. Warm air enters the basement windows, is cooled by the basement concrete, and is then pulled through the rest of the house.

Motorized and insulated backdraft dampers prevent cold air from entering the living space. Uninsulated whole-house fans can be insulated seasonally.

Typical Meteorological Year: Sacramento, California



Choosing Your Fan

Planning a successful installation of a whole-house fan requires a few steps. First, choose the cooling strategy that makes sense for comfort and is within your budget. Then answer the following questions:

- What is my local weather like—at what time of day do temperatures start to drop? At what time does the temperature start climbing?
- Can I replace air-conditioning, either fully or partially?
- How frequently do I need to run the fan—for some, most, or all summer nights?
- Is lower cost more important than features like automatic louvers, low noise level, and power use?
- Is lowering my electricity costs important?

Case 1: Sacramento, California: 3,000-square-foot ranch house built in 1950 with insulation upgrades; four bedrooms, occupied by five people

California has relatively high electrical rates that rise rapidly as electrical consumption increases (tiered rates). The homeowner has just finished paying another $600 summertime electrical bill and he wants to slash that cost. The other inhabitants of the house are noise-sensitive and will make little or no lifestyle changes to save energy.

Sacramento houses require cooling during a significant portion of the year (see graph, above). However, summers have large temperature drops at night.

Driven primarily by economics, the homeowner chose an automatic-closing whole-house fan based upon the following factors, in order of priority:

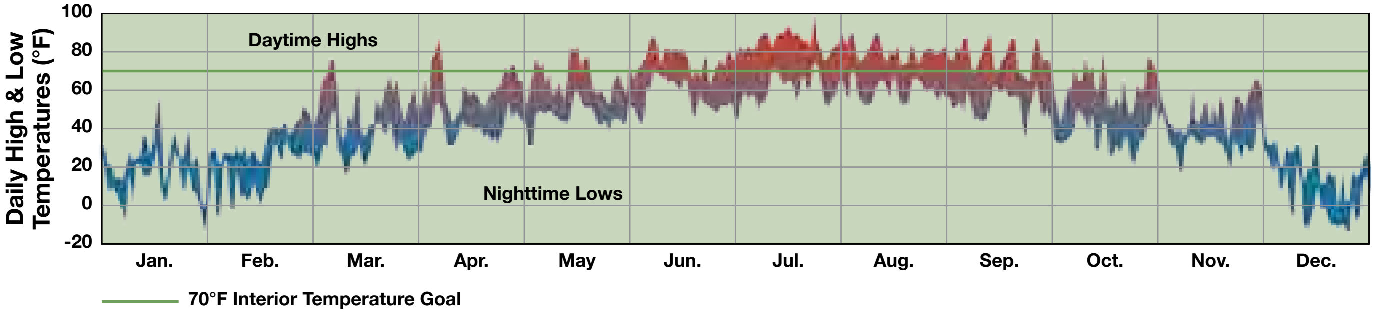
- High airflow to reduced utility bills as much as possible
- Low noise level
- Motorized doors to minimize the inconvenience of having to seasonally weatherize and insulate around the unit
- Fan with low power usage on low speed

Case 2: Aurora, Illinois: similar construction as Case 1, but with two occupants.

Illinois has low electrical rates, with short—but humid and hot—summers and cold winters. The homeowner chose a traditional, uninsulated whole-house fan driven by the following factors:

- Low first cost
- Older central air-conditioner
- Noise level was not critical (fan placed at end of large house)
- Homeowner does not mind insulating the whole-house fan seasonally

Typical Meteorological Year: Aurora, Illinois



Climates that undergo large temperature drops at night (10°F or more below indoor temperature) and houses with lots of thermal capacity are ideal matches for whole-house fans. In these situations, a whole-house fan can easily replace air-conditioning. Most other areas within North America offer some degree of natural cooling potential. For example, climates with hot, humid summers can make use of natural cooling during the spring and fall. See the "Typical Meteorological Year" graphs that illustrate the daily ranges.

Fan Placement

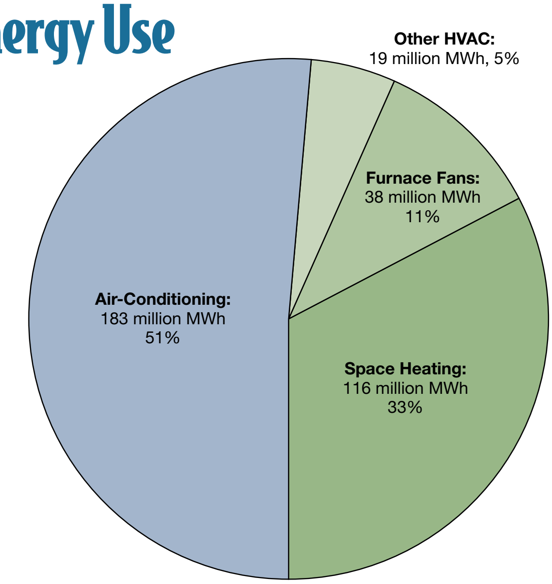
Just about any central location may be a good location for a whole-house fan. To reduce noise from the fan, you'll need to consider acoustic reflection or simply the distance the fan will be from listeners. Because of decorating choices, and the fact that it's a central location for airflow, the vast majority of whole-house fans are installed in hallway ceilings. Airflow paths through the house can be determined by which doors and windows will be opened to ventilate the house.

Attics are the preferred locations for whole-house fans for several reasons. Attics are vented and offer lots of space for equipment. They also allow the fan to exhaust the hottest air in the house. For houses without attics, homeowners may choose alternate fan locations, such exhausting to a garage or crawlspace. There are a limited number of roof-mounted whole-house fan on the market, although this market will undoubtedly grow as more sealed attics are built.

Most whole-house fans are designed to sit on top of the ceiling joists. Typically, cutting joists is unnecessary—the area directly below the whole-house fan is framed to form a channel for the air and support for the grille or backdraft damper. Modern whole-house fans have motorized and insulated doors. If a homeowner opts for a non-insulated model (they are significantly cheaper), then manually insulating the fan in winter is highly recommended. Several whole-house fans use a remote fan connected to the plenum box with flexible ducting, which is a great acoustical attenuator. Pulling air through a duct consumes extra electricity, a consideration when you're weighing energy use. However, with careful selection of motors and fan blades, this energy cost can be minimized.

To improve whole house airflow, and reduce the visual impact, fan intakes are often centrally located in hallways.

Space Heating & Cooling Energy Use



Total U.S. Electrical Consumption for HVAC:
356 million MWh

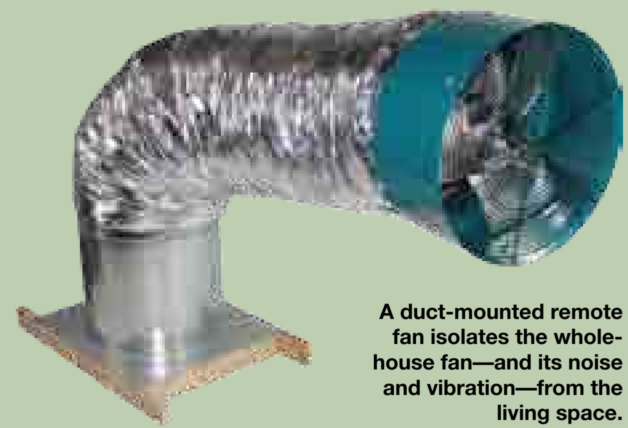
Source: EIA, Residential Energy Consumption Survey 2001, forms EIA-475-C, E & H and other

Acoustics

Acoustics is a complex study, with the additional difficulty of trying to quantify that every person perceives sound differently. Any sound source is a mix of multiple frequencies, each with different power levels. In response to this, acoustical engineers have developed single-digit parameters like sones and decibels (dBA). Engineers prefer the dBA, a logarithmic measure, to sones, since they are meant to correspond to the sensitivity of the average human ear and its varied response to different frequencies.

A common measurement for fans is to measure dBA 1 meter away from the inlet grill at 45 degrees. Actual installation conditions can affect the sound level in a room. For example, a "live" room with hardwood floors and wood furniture will be much noisier than a "dead" room with carpeted floors and upholstered furniture.

Fan noise ratings vary from 50 dBA to 70 dBA. Note that 10 dBA is considered a doubling of perceived sound.



A duct-mounted remote fan isolates the whole-house fan—and its noise and vibration—from the living space.

Ventilation Requirements

Fan Volume (CFM)	Attic Ventilation Required, NFVA (Sq. Ft.)	Doors & Windows Inlet Opening Area (Sq. Ft.)
500	1	2
1,000	2	4
1,500	3	6
2,000	4	8
2,500	5	10
3,000	6	12
3,500	7	14
4,000	8	16
4,500	9	18
5,000	10	20
5,500	11	22

Note: Requirements based on HVI-916 formula for NFVA, with maximum pressure of 0.05" water column for attic; 0.01" w.c. For house. CFM=144 x sq. rt. (.05)/0.0592

The most basic whole-house fans are equipped with self-closing dampers (aka backdraft dampers), which close by gravity and open when air pushes against them. These backdraft dampers offer basic protection against debris (and rodents) from entering the house, but have no insulating qualities. Whole-house fans with insulated doors require motorized actuators to open and close the doors, since airflow alone is not capable of moving anything but the lightest of blades.

Since whole-house fans discharge into the attic, it must be sufficiently vented so that pressure does not build up. Otherwise, fan performance can be jeopardized and pressure buildup could force air back through openings in the ceiling, along with dust and other particulate matter. Whole-house fan manufacturers publish the requirement for attic ventilation in terms of square feet of net free area. This parameter (also known as net free ventilation area—NFVA) was devised to approximate the equivalent of an unrestricted opening. As shown in the table (above), velocity through each vent should be about 500 feet per minute to maintain a safe attic pressure. Most roof vent manufacturers will stamp the net free area required on the vent body as well. If manufacturer's data is not available, several online venting calculators are available (see Access).

Efficiency & Economics

Computer software can predict energy performance quite well, including how whole-house fans will cool a house. The challenge is that all the data about your house, such as how the walls and roof are constructed; the insulation levels; window and door details and locations; and shading (trees, houses); all has to be manually input. This data-gathering could be a significant project on its own. Some energy modeling software is free (see Access).

Foregoing modeling—and ignoring the best way to save on cooling energy (sweating it out or heading for the lake)— it's possible to compare how much energy a whole-house fan versus air-conditioning will save. Just use this simplified formula:

Energy saved per day (kWh/day) = [hours of fan operation x {CFM x ΔT x 1.08 x AC tons x 1,300 AC W/ton (the effective cooling of the WHF)} ÷ 12,000 – whole-house fan W] ÷ 1,000 W/kWh

Example: A whole-house fan runs for 11 hours at night, with an average temperature differential of 10°F, and pulls 4,400 CFM, while using 700 W:

Energy saved per day (kWh/day)= [11 hours/day x (4,400 ft.^{3}/min. x 10°F x 1.08 AC tons x 1,300 AC W/ton ÷12,000 – 700 W)] ÷ 1,000 W/kWh = 48.93 kWh/day

A larger airflow can compensate for smaller inside-versus-outside temperature differentials, such as those that occur in the early evening or during humid weather. However, there comes a point where overpowered and/or inefficient whole-house fans may be less efficient than air-conditioning.

The simplest method to determine the economic viability of a project is to use "simple payback"—dividing the capital cost by the annual savings. This is a great method of quickly assessing whether the project makes sense for your particular situation.

Example: This equation plugs in information from Case 1 data, using PG&E as the utility. With that utility's tiered rate structure, it's very easy to reach tier 3 (above 645 kWh/ month), which has a rate of $0.29/kWh. Assuming a WHF first-cost of $2,400 (installed) and annual usage of 90 days:

Payback = $2,400 ÷ (90 days/yr. x 48.9 kWh/day x $0.29/ kWh) = 1.88 yrs.

Environmentally minded folks might be interested in calculating their carbon offset in cost per ton of carbon dioxide (CO_2) avoided. To figure dollars per ton of CO_2, take the capital cost of a project and divide it by the lifetime avoided carbon dioxide emissions. This figure is generally given in dollars per metric ton (2,200 pounds). Even the most full-featured units deliver CO_2 avoidance between $30 to $50 per ton.

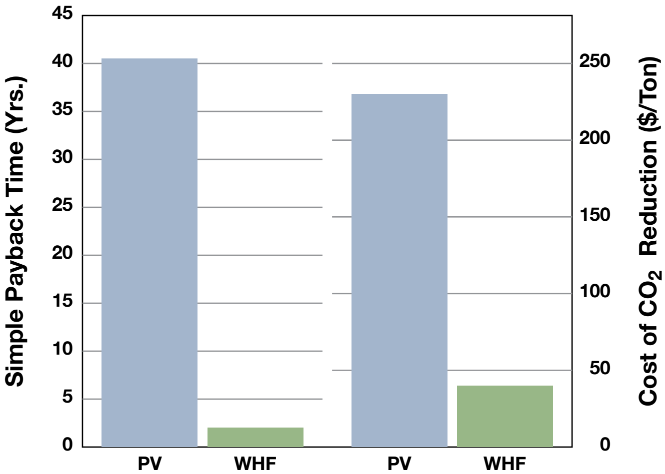
Example: Using the 4,400 CFM fan data: Dollars per ton of CO_2 = $2,400 (installed first-cost) ÷ (48.93 kWh/day x 90

Automatic Fans

Can whole-house fan systems be automated? Certainly, it's technically straightforward to devise a method that turns on the whole-house fan when cooling is required and outdoor temperatures drop below indoor temperatures. However, since large openings are required for inlet airflow, doors and/or windows also must be opened—a more difficult undertaking for automation. For now, motorizing an existing door or window is a custom project.

Because operating whole-house fans usually involves opening a window in the living space, automation is atypical. But it is possible.

Benefits of Whole-House Fans vs. Photovoltaics



days/yr. x 20 yr. lifetime x 1.3 lbs. CO_2*/kWh) ÷ 2,200 lbs. CO_2/metric ton = $46/mTon CO_2 saved

*EPA estimate, based on the U.S. electrical mix

Whole-house fans allow homeowners to naturally achieve comfortable indoor conditions while minimizing energy use and improving indoor air quality. This is a simple project that springboards on existing technology, and by economic and environmental measures, offers a quick payback on investment. If only 1.1% of the U.S. households replaced air-conditioning with whole-house fans, the output of an average coal-fired power plant—3.95 billion kWh—would be saved.

Incentives

Many electrical utilities have whole-house fan rebate programs. Incentives range from $50 to $250, and generally require only that the recipient to be a current utility customer. Check out an online database of rebates at dsireusa.org.

Access

Neil Smith (neil@airscapefans.com) has spent the last quarter-century in the HVAC world, having obtained a degree in building engineering. He is a mechanical engineer, with his professional interests focused on energy efficiency.

DOE-2 based building energy use and cost analysis software • www.doe2.com

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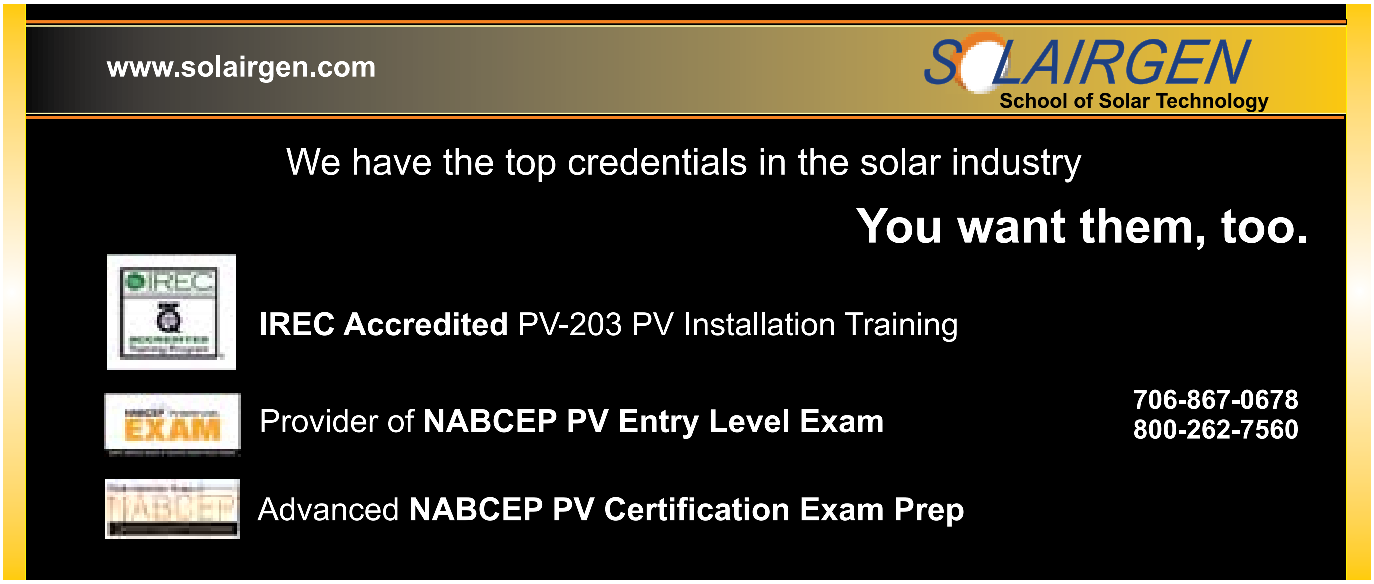
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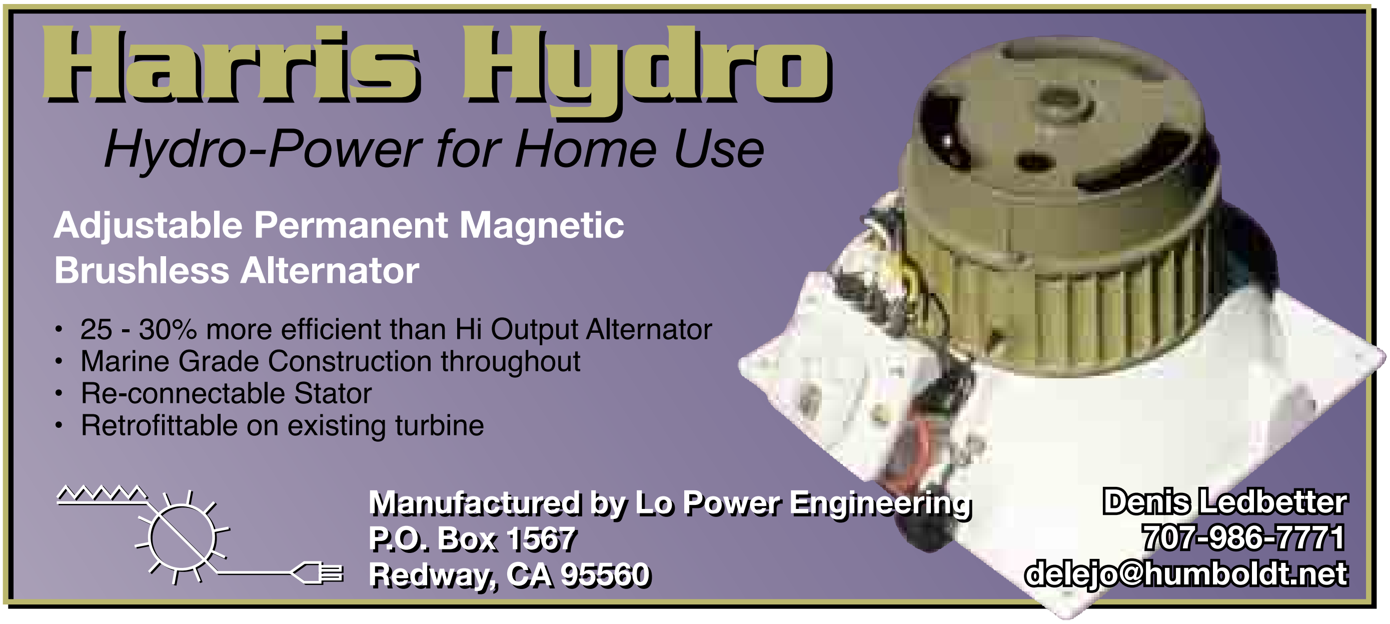
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Off-Grid Appliances

Ultra-Efficiency Required

by Ian Woofenden

Mike Flippo Photography

If you're on-grid, energy efficiency is important. It saves you dollars and reduces your environmental footprint. But it's even more important if you're off-grid—or planning to move off-grid.

Renewable energy (RE) systems generally produce electricity that is more expensive than heavily subsidized grid electricity, with all its socialized costs and impacts. The utility grid also provides you with essentially unlimited electricity 24/7/365, without a need for storage. This makes renewable electricity seem expensive by comparison (though it really isn't if you look at the big picture).

Why Ultra?

Off-grid RE systems must provide for *all* the electrical energy you want, day or night and no matter the weather. There can be several consecutive days with little sun or wind—and even when it is sunny or windy, you need a buffer between your energy sources and your energy loads. This means a battery bank, which is costly and also limited in capacity. Your backup for when energy production and the battery is low is not the utility grid, but usually a noisy, polluting, and expensive fuel-fired generator.

All of this is why, in 1984, at a time when I was not accustomed to spending thousands of dollars on anything, I bought a $2,500 refrigerator. This was shocking to my on-grid neighbors, who couldn't imagine why I would spend so much

It may look easy, but operating and maintaining an engine generator is a dirty, loud, and expensive way to make energy.

© iStockphoto.com/lisafx

on an appliance, when nothing else on my property had cost that much.

The explanation was clear: If I had purchased the lowest-cost fridge from the local appliance store, I would have had to spend many more thousands of dollars on additional RE gear to power the initially cheap—but lower efficiency—fridge. Energy efficiency is often the best investment you can make, if you take the long-term view.

How About DC?

My fridge is direct current (DC), a choice I might or might not make today (and would be much less likely to make for a client). Going with DC avoids the losses inherent in an inverter, which converts PV and battery DC to conventional alternating current (AC)—the electricity type most people are used to. This makes a simpler system in some ways, since the batteries are tapped directly.

When I started with RE, efficient inverters were non-existent. So my home still uses a lot of DC. The drawbacks to this strategy are that DC is not conventional, so it's not always easy to find appliances, and some appliances—made for the RV and marine industry—are not as efficient or robust as their AC counterparts.

Sun Frost's DC refrigerators and freezers are highly efficient units that don't require an inverter. High-efficiency AC models are also available.

Courtesy Sun Frost

© istockphoto.com/alex_kz

High-efficiency compact fluorescent bulbs are a cheap and easy way to reduce energy loads on- or off-grid.

The other drawback is that you'll typically end up with dual household wiring systems, because very few people can live with *only* DC. Most often, AC appliances are also desired, which means having two sets of wiring (DC and AC), a more expensive option. Usually the wisest choice for a modern, whole-house system is to choose all AC, buy an efficient inverter, use ultra-efficient appliances, and add a bit more energy capacity to the system to cover the inverter losses.

Phantoms Loom Larger

For large residential RE systems, small phantom loads (appliances that use energy when "off," or for no useful purpose) are not necessarily a big deal. It's important from an environmental point of view to reduce or eliminate them, but they are not deal-breakers when the grid or large renewable generating capacity is available.

The ultra-efficient SunDanzer chest-style fridges and freezers run on DC.

Courtesy SunDanzer

Courtesy Bosch USA

This Bosch dishwasher saves energy by using (and thus heating) only 1.6 gallons of water per load—159% better than the DOE's energy-efficiency standards.

Staber offers efficient horizontal-axis washing machines that are top-loading.

Courtesy Staber Industries

When you consider smaller off-grid systems, phantom loads can make or break a system. A 5-watt phantom wastes 120 watt-hours (Wh) per day. If your large home system or on-grid home uses 30 kilowatt-hours (30,000 Wh) per day, 120 Wh is small change. However, for small off-grid systems—for instance, ones that may *generate* less than 1 kWh per day to power some lighting—*any* phantom load is bad news. And in a typical home, the phantoms can easily add up to 5 kWh or more per day.

If you must have appliances that are phantom loads, I suggest pre-wiring switched outlets in your new home, so you can easily turn off the phantoms when the appliances are not in active use. Less graceful alternatives are plug strips, individual switches, and pulling the plug. The most common phantoms in a modern home are found in the computer center, entertainment center, and kitchen. Take a watt-meter into the store to check for phantoms before you buy, if possible.

Specific Loads & Specific Solutions

When it comes to making load choices, off-grid folks without deep pockets always focus on efficiency. Here's some specific advice on common appliances, drawn from my 30 years of off-grid living experience.

- **Refrigerator/freezer:** Set your sights on extreme energy efficiency here, since this is frequently the biggest electrical load in an off-grid home. Refrigerators and freezers cycle on and off continuously, and need to run regardless of sun and wind—you can't flex your use to accommodate the variations in weather. Using specialty DC appliances may be a good option in some cases, and getting accurate numbers on energy use before you buy any refrigeration equipment is the best idea. Prepare to spend more up-front for better overall cost savings over the long term. At least one ultra-efficient fridge is also available in an AC configuration for about the same cost.

- **Lighting:** Off-grid homes of sensible design have no incandescent lights. Compact fluorescent lights (CFL) and LEDs predominate. Try a variety of CFL and LED options, since quality, color rendition, and light output varies.

- **Clothes washing/drying:** Horizontal-axis (generally front-loading) machines use less electricity (and less water, requiring less water heating and pump operation) than top-loading vertical-axis machines. Check your machine for phantom loads and use a timer or switch when necessary. Off-grid homes will rarely use an electric dryer, and if solar energy (a clothesline!) can't be used, a propane dryer is an option.

- **Motor loads:** In the old days, I switched most of my woodshop motors to DC, a smart move in those days of inefficient inverters. Today, it makes sense to choose high-quality, sometimes variable-speed AC motors; whether for pool pumps, heat-pump motors, shop tools, or

anything else that is motor-driven. The bottom line is found with your watt meter, which will tell you how much energy is being used.

- **Computing/office electronics:** A single word gives you the core of my advice here—laptops. These typically use half or less what a desktop machine uses, and they also incorporate a battery, so in times of very low renewable input, you can still use your computer for awhile. Peripherals—printers, routers, modems, backup drives, scanners, etc.—often are phantom loads, so put them on individual switches and turn them on only when needed. These peripherals do not usually need to be on for long periods of time, so ultra-efficiency may not be as crucial as for the computer itself.

© iStockphoto.com/okea

Laptops offer all the computing power of desktop computers, while using a fraction of the energy.

- **Solar hot water systems:** For off-gridders, solar hot water systems reduce the need for propane—making hot water with solar electricity is not an intelligent option. Often it's wise to make the electrical portion (for the solar pumps) separate from your main system to reduce the unpredictable load on the main electrical system. I like PV-direct systems that use a dedicated PV module to run the SHW system pumps.

A Mind-Set You Can Bank On

Being aware of your energy resource can make off-grid systems much more effective. Off-gridders soon learn that it's better to do laundry when it's sunny than to draw on limited battery capacity and do it at night.

Well-designed off-grid systems will produce a significant surplus of energy at times, since they are sized based on the worst-case scenario. Instead of wasting this energy, you'll want to take advantage of it.

Ben Root

PV- and engine-generated electricity are too expensive to use for heating water. Instead, use a solar collector to make hot water directly from sunshine.

© iStockphoto.com/polarica

When the batteries are full and the sun is still shining, the author uses the surplus energy for "opportunity" loads, like laundry or cutting firewood with an electric chain saw.

Having "opportunity loads" to use surplus energy is a good strategy. At times, I can get a lot of my winter firewood cut with an electric chain saw, using energy during long sunny days, or during long windy times when much of the energy would be wasted. This has the added benefit of avoiding the noisy, polluting, gasoline-powered chain saw.

Focusing on energy efficiency in your appliance purchasing and operation choices can save money on up-front system cost. It also will reduce your pollution, ongoing generator costs, and battery replacement costs.

The advice here is crucial for off-grid folks, but also useful for all users of electricity. Taking the off-grid, ultra-efficiency mind-set into your on-grid home will shrink your bill, your footprint, and the cost of your future renewable energy system, too.

Access

Ian Woofenden (ian.woofenden@homepower.com) has lived off-grid for almost 30 years in northwest Washington's San Juan Islands, and lives to tell the tales.

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17. I certify that the statements made by me above are true and complete. Scott M. Russell, Operations Director, 9/27/10.

GAVIOTAS

Building a Sustainable Community

by Laurie Guevara-Stone

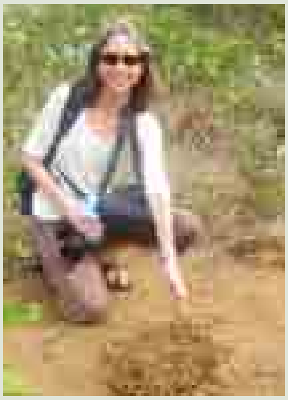
Gaviotas, Colombia, founder Paolo Lugari at the community meeting hall.

Nearly 40 years ago, Paolo Lugari, a young, idealistic development specialist, united a group of scientists, artisans, street kids, and local Guahibo Indians with the common cause of building an eco-village in the bleak eastern plains of Colombia, some 300 miles east of Bogota, the country's capital. His rationale: "If humanity is to survive, we must move out of the cities, and learn to live sustainably in areas where people have not tried to survive before."

Through trial and error, Lugari and this remarkable group succeeded in designing sustainable technologies for the tropical climate, and transformed 20,000 acres of once-barren land into a regenerated rain forest. Today, the village of Gaviotas is home to 200 people and revered by the United Nations as a model of sustainable development. The people, known as Gaviotans, manufacture their own solar hot water collectors, windmills, and a highly efficient water pump. They produce all of their own food, and earn an income through the sale of their renewable energy products, sustainable forest goods, and spring water.

In March 2010, I visited this extraordinary community to see firsthand the secrets of its success. Friends of Gaviotas, a U.S.-based nonprofit group, coordinated a two-day tour for a group of people interested in sustainable development.

A Gaviotas resident plants trees in the row created by the biodiesel-powered tree planter.



Visitors to Gaviotas each plant a ceremonial tree as part of their tour.

Creating synergies is part of the Gaviotan way. Mycorrhiza, a beneficial fungus, helps the newly planted trees absorb nutrients.

Bogota Beginnings

Our visit began with a stopover at Gaviotas headquarters in Bogota, which serves as a business office and a distribution hub for the community's renewable energy products and forestry goods.

We spent the better part of the morning rapt in discussion with Lugari, who captivated visitors with tales of the Gaviotans' early years and his poetic philosophies on the importance of "replenishing the vegetable skin of the earth." He underscored the fact that trees can absorb the carbon dioxide gases we produce, and advocated that planting a tree can help save humanity—a point he drove home with an overview of Gaviotas' reforestation efforts.

In its three decades, Gaviotas has planted 8 million trees and cultivated the largest planted forest in Colombia—without using any fertilizers or chemicals. To accomplish such a feat with a relatively small work-force and resources, Gaviotas engineers built an efficient, biodiesel-fueled tree planter—a double-row planter that can plant one seedling every three seconds, or 250 acres in a 24-hour period.

The community began planting Caribbean pines in the early 1980s. Rather than adhering to conventional forestry practices, the Gaviotans experimented and developed site-specific methods that work with the tropical climate. The key is a small fungus called mycorrhiza—a very important part of Gaviotas, according to Lugari, who says, "Life is sustained by the things you don't see." The fungus, which doesn't occur naturally in the area, had to be brought in from the jungles of Honduras and Guatemala, where foresters used it to treat soil on pine plantations. The fungi's spores bond with the roots of the trees and aid in the absorption of nutrients in the region's highly acidic soil.

Innovations through Experimentation

According to Lugari, the community thrives on overcoming obstacles through experimentation. People are encouraged to read academic texts but with a critical eye, and approach problems without any preconceived notions of what can or cannot be achieved. "The only fixed idea in Gaviotas," Lugari

Striking Liquid Gold

After planting the first of their Caribbean pines, Lugari and his team realized that the golden resin produced by the bark of these trees can be turned into rosin, which is widely used in a variety of commercial products and could be sold to generate income for the village. The resin naturally regenerates beneath the surface of the bark, and, if extracted properly, the trees are not damaged. With the support of several international and domestic grants, they expanded the forest and developed sustainable practices for harvesting, refining, and packaging the resin. In the two decades since, production has increased to 1,500 tons of rosin a year and generates 80% of the community's revenue.

Resin harvested from the Caribbean pine plantation is processed and turned into rosin, providing income for the community.

Flat-plate collectors made by the Gaviotas residents are used throughout the community and in the city of Bogata.

This Bogata, Colombia, hospital boasts the largest solar hot water system of any hospital in the world—and uses Gaviotas-made collectors.

says, "is that nothing is done that is not sustainable in the final balance."

Maintaining this freethinking atmosphere has meant doing away with some outside influences—most notably, the Internet. After two years, the community decided to disconnect its solar-powered Internet connection and "return to thinking." According to Lugari, the community determined that Web access was stifling its progress—people were turning to the Web for preconceived ideas rather than working together to dream up innovative solutions for tasks large and small.

Such large-scale innovations include a solar hot water system that produces hot water even on overcast days; a windmill that pumps thousands of gallons of water per day from a depth of more than 120 feet; and a unique "sleeve" water pump that can extract water from much deeper depths than a conventional pump, with far less manual effort (see "Sustainable Designs" sidebar).

That afternoon, we got our first glimpse at the village's technologies at work, as Lugari led us on a tour of a few Gaviotas-manufactured systems in Bogota. By far, the most impressive is the solar hot water system at the Hospital Universitario Mayor Méderi—the largest SHW installation on a hospital in the world. Six hundred flat-plate collectors mounted on the roof of the main building and its adjacent emergency room provide 100% of the hospital's hot water. Equally inspiring was Sausalito, one of many Bogota neighborhoods equipped with Gaviotas solar hot water collectors. One thousand apartments in multiple, multistory buildings are outfitted with individual solar hot water systems—with one collector per unit and spherical water-storage tanks.

Gaviotas' reach extends far beyond the capital city. All 30,000 solar hot water collectors installed throughout the country are manufactured by Gaviotas, and the community's sleeve pump is being used in more than 600 rural villages.

A hand press is used to create earthen-cement bricks that make up many of the buildings in Gaviotas.

The Gaviotans' multiuse meeting hall (left) and this traditional house (above) are constructed of hand-pressed, earthen-cement bricks.

Village Design

The next morning, we departed for Gaviotas on a chartered plane. As we descended over the savannah into the village, we began to fully appreciate what Lugari and his team had accomplished. Acres upon acres of trees appeared amid the desolate desert that is the Los Llanos region. The contrast of the tree plantation against the barren, sun-baked lands was awe-inspiring.

Upon touching down on the dirt landing strip in Gaviotas, we were greeted by a small group of Gaviotans and led a short distance to the forest where we each planted a small acacia tree—further impressing upon us the importance of trees to the community's mission. We then boarded our transportation for the day: an old mini-bus towed by a biodiesel-fueled tractor.

Our first stop was the multipurpose hall, which serves as the meeting place, church, conference center, and game room. The most striking feature of the hall is the roof—a stainless steel parabola that was designed to optimally reflect the sun's rays at any given time throughout the day and keep the interior cool. Like most buildings in Gaviotas, the hall is built of brick-sized, pressed blocks made from a mixture that is mostly native soil, with a little cement. These are hand-made in Gaviotas with a CINVA (a Spanish acronym) manual press, developed in Colombia, and refined and tested in the community of Gaviotas. The thermal mass of the pressed blocks helps keep the interior of the building cool.

One interior wall of the hall is covered with the colorfully painted mural that depicts the last 30 years of Gaviotas. Lugari talked us through that history and gave us some insight into everyday life in Gaviotas—where there are no laws, no police, no jails, no mayor, no weapons, and, as Lugari emphasized, no theft or corruption.

Using Natural Resources Wisely

From there, we drove into the forest groves. Though only three decades old, the forest is as dense and diverse as some of the world's most mature rain forests, boasting hundreds of species of native flora and fauna. Such rapid growth, as Lugari explained, is largely due to a series of deliberate and accidental choices. Instead of weeding out other plants that sprouted up and might have competed with the trees' roots, the village agriculturists let nature take its course, allowing the forest floor and neighboring grasses to flourish. In time, the canopy of the Caribbean pines nurtured the return of native fruit trees, plants, and animals, and the emerging forest fostered an additional 10% rainfall annually.

From the forest, we moved onto the resin distillery—the heart of the Gaviotan economy, where resin from the pines is distilled into two marketable by-products: rosin and clear

This colorful mural captures the spirit of community in Gaviotas.

This electric generator uses biodiesel to power the biodiesel fuel-making plant.

turpentine (see "Striking Liquid Gold" sidebar). The row of bicycles parked in front of the distillery is a testament to the healthy lifestyle of the car-less community. The state-of-the-art distillery, designed by Gaviotas engineers, runs off biodiesel, and like many of the residences, is adorned with beautifully carved Gaviotas art.

Adjacent to the distillery is the biofuel plant, where a mixture of pine-turpentine and used cooking oil is refined into biodiesel. The used cooking oil is collected from restaurants in Bogota—instead of returning empty after delivering the rosin and turpentine to the Gaviotas headquarters—the trucks collect drums of used oil. The biodiesel is used to run *all* of the diesel engines—electric generators, tractors, and trucks—in the village, including the generators that power the biodiesel plant. Filtered cooking oil is poured into a large tank, where methanol and a catalyst are added. After about an hour of mixing, the contents are pumped to a large settling tank, where the glycerin falls to the bottom. The biodiesel then gets washed and transferred to a storage tank. The process yields roughly 100 tons of biodiesel annually.

Next up to visit was the water purification and bottling plant—a glass and steel structure that was once a hospital. The building was converted by the Gaviotans into a water purification and water bottling plant in 1995 after realizing they could improve people's health by distributing clean water. Shortly after Lugari and his team founded Gaviotas, they discovered that the aquifers supplied a consistent source of clean water and developed a windmill to pump water into a storage tank, where it is gravity-fed to the bottling plant. A portion of the sales of their water to restaurants in Bogota help Gaviotans provide free water to the local communities.

Though the water bottles are made from petroleum-based plastic, the Gaviotans have found innovative ways to give them a second life. The bottle is designed with a unique interlocking shape, so it can double as a Lego-like toy once it is empty. Alternatively, the bottles can be filled with sand and used as interlocking building blocks for walls, a strategy used to construct several buildings in the village. The remaining bottles are collected and sent to a recycling factory in Bogota, where they are turned into carpets, clothes, and other materials.

Renewable Electricity at Gaviotas

The water purification and bottling plant is one of two places in Gaviotas that use solar electricity, the other being the telecommunications center, where they communicate with the outside world. The telecommunications center has a stand-alone 4.5 kW PV system, with dry-cell batteries that are changed out every five years. The Gaviotan philosophy of self-sufficiency—not using imported technology—keeps solar electricity out of the picture for the most part. The

Windmills pump water to storage tanks, where it is gravity-fed to the purification and bottling plant.

A seesaw turns the chore of pumping water into child's play.

Stacked into a wall, used, sand-filled plastic water bottles get a second life.

Sustainable Designs

Solar Hot Water System— To ensure a highly efficient flat-plate collector, Gaviotas engineers stripped a copper sheet in nitric acid, then oxidized it with a solution of copper sulfate dissolved in hydrochloric acid. The outcome is a deep black color, deposited directly on the copper, resulting in a solar collector so efficient that water is heated to 120°F even on overcast days. Street kids turned solar hot water technicians manufacture the collectors in the Gaviotas factory in Bogota.

"Sleeve" Water Pump—Typical hand pumps require a person to lift a piston to make the water rise. In the Gaviotas sleeve pump, the piston stays in place inside a lightweight plastic sleeve, and the sleeve is lifted instead. This design requires much less effort and enables water pumping from much deeper wells than a conventional hand pump—its submerged piston and cylinder allow it to operate in wells with water depths greater than 10 meters. Gaviotan engineers took this idea one step further, coupling the sleeve pump to a seesaw, turning a common children's playground toy into a life-nurturing technology that can provide clean water to rural communities.

Windmill Water Pump—After building 58 different models of windmills over nine years, Gaviotan engineers finally hit on a simple and inexpensive design to suit Gaviotas' tropical climate. Building off of ideas from Holland, Australia, and Africa, the village designed a windmill that pumps thousands of gallons of water per day, and can operate at wind speeds as low as 4 miles per hour. The windmill has five aluminum blades, patterned after landing flaps Gaviotan engineers spotted in a NASA airfoil catalog, each turned inward to eliminate the need for a tail. It drives a double-acting stainless steel piston pump. The result is a windmill that is 10 times lighter than a traditional windmill, needs three times less wind, and does not need to be stopped in a storm.

Hydraulic Ram Pump—The Gaviotas Hydraulic Ram can pump thousands of gallons of water, day and night, to a maximum distance of 1,000 meters with a height of 100 meters, without electricity or fuel consumption. The ram pump uses the force of falling water, developing pressure that lifts to a point higher than where the water originally started.

majority of the plant is run on biodiesel and microhydro-generated electricity, but some of the water-analysis labs run their equipment from a 3 kW PV system. Keeping the plant cool is accomplished passively with underground ventilation ducts that funnel prevailing winds through the plant and out of the "self-cooling" roof, made of two sheets of corrugated roofing bonded together to create honeycombed air chambers.

The last stop of the tour was the microhydro plant, which produces up to 20 kilowatts, with a 1 meter of head. This plant produces the electricity used in every home throughout the community.

As we made our way back to the airstrip at the end of the tour, a drizzling rain hastened us onto the plane. Time was of the essence, since heavy rains during the wet season have been known to ground planes for weeks. As the plane made its ascent and Gaviotas slowly disappeared, I fully understood what Lugari had said earlier in the day: "Gaviotas is not a community that can be replicated. What needs to be replicated is the Gaviotas way of thinking."

Access

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Friends of Gaviotas • www.friendsofgaviotas.org • Info & hosted visits • A trip to Gaviotas is being organized for November 2010.

Gaviotas: A Village to Reinvent the World, by Alan Weisman (2008, Chelsea Green Publishing Co.)

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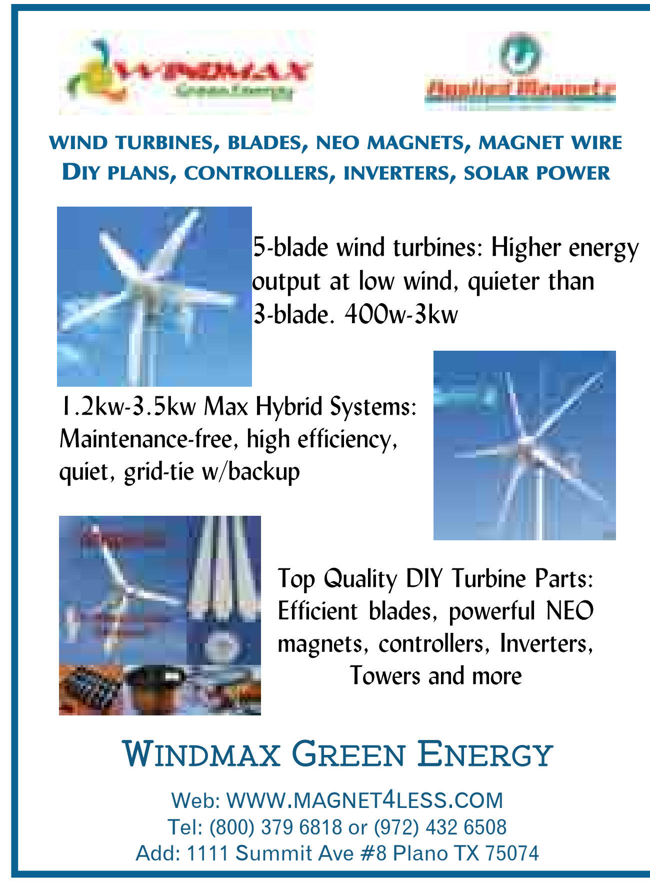

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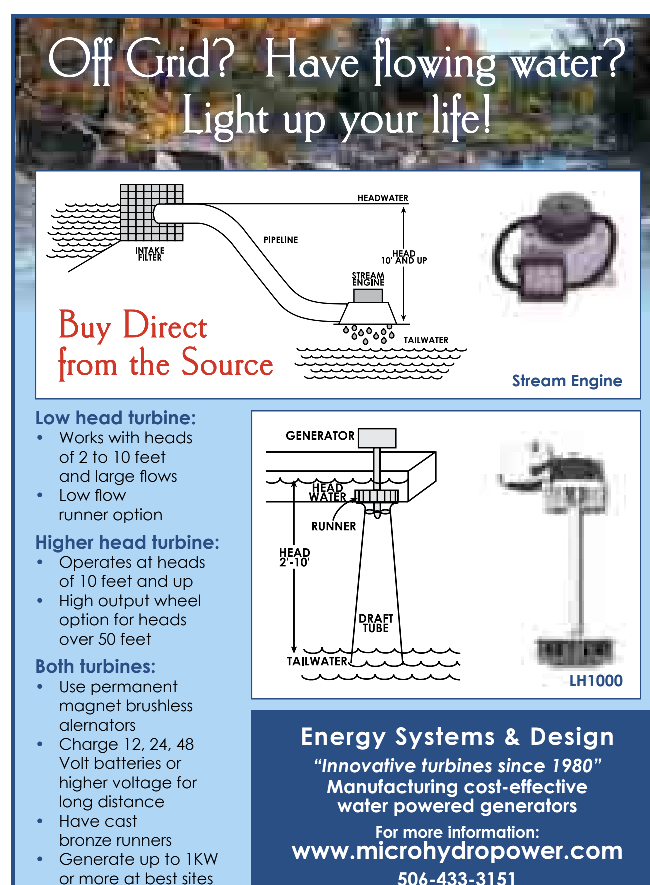

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Utility Interconnections & the *NEC*

by John Wiles

Section 690.64 of the *National Electrical Code (NEC)* continues to puzzle inspectors and installers with the requirements that apply to the connection of grid-tied inverters to the premises wiring and to the utility. This article should clarify some of those requirements. For details, refer to previous *Code Corner* articles (see Access).

A Diagram is Worth 1,000 Words

This diagram applies to several types of grid-tied PV systems. These systems all start with a meter connected to the utility. Next to that may be an existing service disconnect and the connected existing load center or a PV supply-side connection, which is just a second service entrance on the existing premises wiring system.

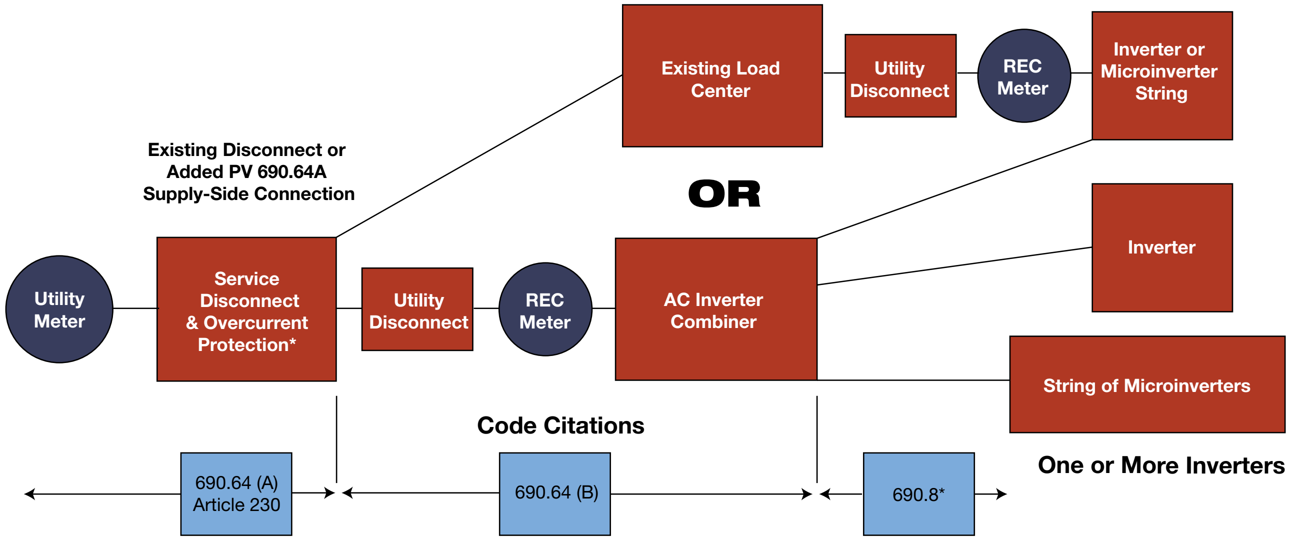
In either case, *NEC* Article 230 (which covers service conductors and equipment) requirements apply (as noted at the bottom of the diagram). In most jurisdictions, the utility will require a PV disconnect on the AC output of the PV system. In many cases, a renewable energy credit (REC) meter is used to measure the PV system output. There are many different scenarios to consider, such connecting one or more inverters or strings of microinverters or AC PV modules to the added combining panel. Alternatively, a single inverter could be connected to an existing load center. In some cases, multiple inverters might be connected through an AC combining panel and then back-feed an existing load center. Another scenario might use a microinverter string connected through an AC disconnect and then back-fed to the existing load center.

Inverter Output Circuit

All grid-tied inverters have a rated output current that cannot be exceeded. There are no surge currents in these output circuits and *NEC* 690.8 requires that the circuit and the overcurrent protective device (OCPD) be rated at 125% of that rated output current. When the calculated OCPD value is a nonstandard value, the next standard higher value should be used, but this should not exceed the maximum overcurrent value given in the inverter's technical specifications. Conductor size should be selected so that it is protected by the OCPD rating.

The note in the diagram indicates that *if* there is an

Grid-Tied Inverter Connections & Their *NEC* Code Sections



*Note: If OCPD is installed at inverter, then 690.64(B) applies.

overcurrent device mounted at the inverter, then the requirements of 690.64(B)—and *not* 690.8—will apply. Some installers and manufacturers use a circuit breaker or fused disconnect at the inverter to meet the 690.15 requirements for a maintenance disconnect at the inverter. The inclusion of an overcurrent device at this location generally necessitates that the output conductors from the inverter be larger—as required by 690.64(B)—than would otherwise required by 690.8.

After the First Inverter Overcurrent Device

Any conductor or bus bar that can have power flowing from more than one source (under normal or fault conditions), such as the utility and an inverter, and where the conductor is protected by an overcurrent device on each source, must meet 690.64(B) requirements. This is the long-standing 120% allowance for when 690.64(B)(7) conditions can be met. Section 690.64(B) applies to all conductors and bus bars from the first overcurrent device connected to the inverter output all the way to the service disconnect.

These bus bars and conductors would include the bus bars of any back-fed main panel boards connected to one or two inverters, or sets of microinverters, and any bus bars in AC inverter combiner panels. The conductors or feeders between the panel boards or load centers and the main service disconnects are also subject to the requirements of 690.64(B)(2).

In general, the ratings of all of the breakers *supplying* a bus bar or conductor are *added* together and the sum is divided by 1.2 (for the 120% allowance) to calculate minimum required bus bar and conductor ratings. If the location requirements of 690.64(B)(7) cannot be met (PV breaker located at the opposite end of the bus bar or conductor from the utility breaker), then the sum is divided by 1, and the bus bar rating or cable ampacity goes even higher.

For example: Two inverters each require a 50 A back-fed breaker in a main lug inverter combining load center to meet 690.8 requirements. A supply-side connection is going to be made with a 100 A fused disconnect. The rating of the combining load center and the ampacity of the conductor to the 100 A fused disconnect must follow the 690.64(B)(2) requirements. As noted, even with a supply-side connection, as soon as the circuit passes through the service entrance disconnect/overcurrent device, all load-side requirements apply, because the PC circuit is now on the load side of the service disconnect.

(50 A + 50 A +100 A) ÷ 1.2 = 200 A ÷ 1.2 = 166.7 A

The numbers indicate that a 200 A inverter load center/panel would be needed because there is no 175 A option available. Assuming a 75°C rated conductor, a 2/0 AWG conductor should be used between that panel and the 100 A fused disconnect.

Now suppose that the two inverters are back-feeding into an existing load center (switchgear) with a 200 A main breaker, and positioning the two back-fed inverter breakers at the opposite end of the switchgear bus bar from the main breaker isn't possible. The requirements of 690.64(B)(7) are not met and the 120% allowance cannot be used. The equation becomes:

(50 + 50 + main breaker) ≤ Bus bar rating

If the main breaker were rated at 200 A, then the bus bar would have to be rated at 300 A.

As the diagram shows, 690.64(B) applies to any panel or load center that has connections to the utility and to the inverter. It can be an existing load center or an added inverter combining panel.

The Main Disconnect & On to the Meter

Any circuit between the utility revenue meter and the service disconnect would be considered a service entrance circuit and be governed by the requirements of Article 230. This would be true if the circuit was an existing service entrance conductor or a new 690.64(A) supply-side connection. The conductor size, type, and routing, as well as the size and location of the service disconnect, would have to meet Article 230 requirements. However, after passing through the overcurrent device on either an existing service disconnect or through the overcurrent device on an added PV supply-side connection, the requirements of 690.64(B) apply all the way to the first overcurrent device connected to the inverter output.

A diagram can simplify understanding of the requirements of *NEC* 690.64. While the PV industry had hopes of getting additional clarity into this section of the *Code*, those hopes were not realized for the *2011 NEC*, and we must continue to work with the existing language.

Access

John Wiles (jwiles@nmsu.edu; 575-646-6105) works at the Institute for Energy and the Environment (IEE) at New Mexico State University. John provides engineering support to the PV industry and a focal point for PV system code issues.

Southwest Technology Development Institute • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html • PV systems inspector/installer checklist, previous "Perspectives on PV" and *Code Corner* articles, and *Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices*, by John Wiles.

Further Reading:

"Inverter Ins & Outs," *Code Corner, HP132*

"Connecting Inverters to the Grid, Part 1: Load-Side Connections," *Code Corner, HP134*

"Inverter Supply-Side Connections," *Code Corner, HP135*

"Common Questions about Grid-Tied Systems," *Code Corner, HP138*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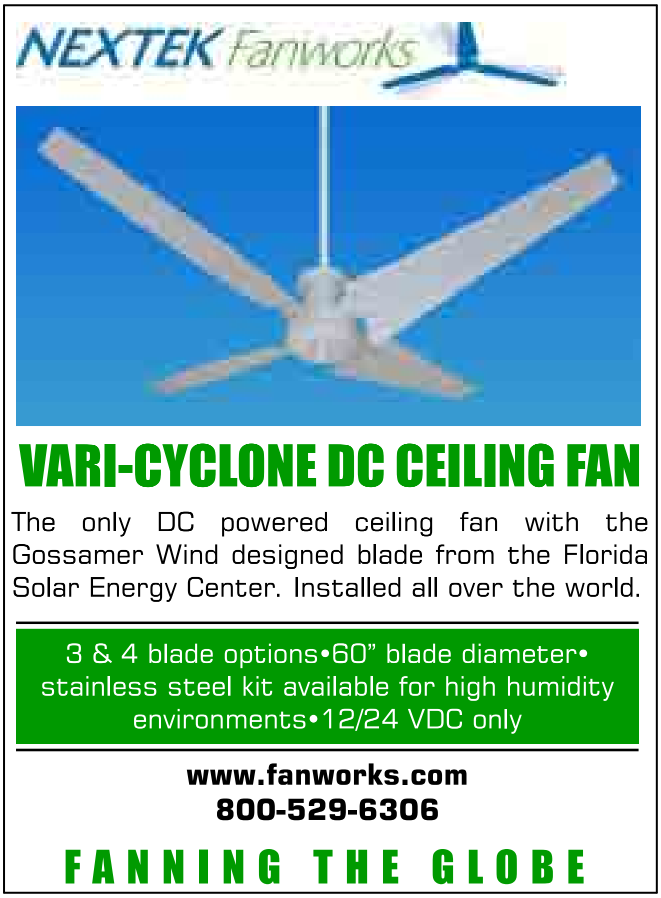
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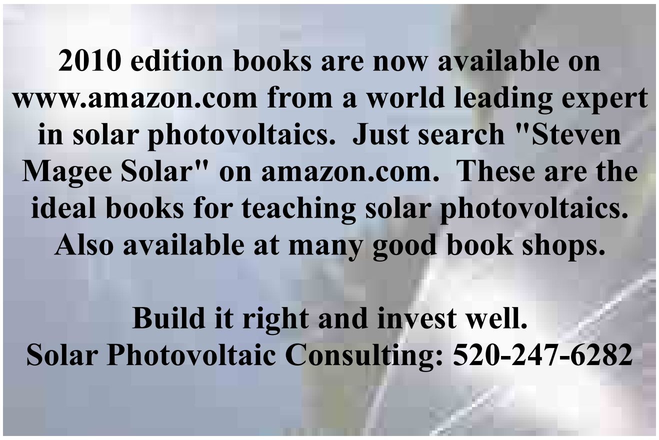
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Containing the Zombie Apocalypse

by Kathleen Jarschke-Schultze

Self-Sufficient, Self-Contained

In our seemingly never-ending quest to be more self-sufficient at our off-grid homestead, a big part of using our own garden, orchard, and vineyard's bounty is processing and storing the harvest. Bob-O, my partner in crime, came up with a solution that would expand our storage capability greatly. His plan was to bury a 20-foot-long steel cargo container in the low hillside next to our recycling and wood sheds.

When we first discussed this project, I wanted to outfit the container as a "refuge of last resort," in case of wildfire. After all, we do live two miles up a dead-end road. Bob-O and his son, Allen, the captain of a wildland firefighting Hotshot crew, laughed at me, and said they would come knock on the door when the fire was over. Apparently, the wide meadow to the north of our house, with its open space and short grass, is a safe enough refuge.

We bought our steel container from a company about an hour and a half north of us. They said they would deliver. We described our location and the two-mile dirt road into our place. They were unfazed—we were very glad. The company guaranteed that our purchase would be leak-free and the massive steel doors at one end would open and close as they were meant to.

Containable

The day of delivery came. I had told Bob-O that he must be present for the event, so we were both home. It was a Monday and the weather was good. The driver called and said he would be there by noon. Around 12:30, he called to say it had been one of those days and he was running late. Everything had gone awry for him that morning. "I can't help but believe God has a plan," he told me.

"Sure he does," I replied brightly, "Tuesday."

Apparently, God's plan was more punctual than I suspected. Two hours later, the truck rolled across our creek ford and through the bottom gate. Bob-O had used our tractor and backhoe to dig an open channel back into our hillside. He spread 6 inches of gravel over the bottom of the channel, which was about 11 feet wide, giving us 3 feet to maneuver. The container was on a truck with a dump bed. We were not sure just how close to our prepared site the driver could get.

The driver was very experienced. He backed up between our house and the old apple tree even though the drive was uphill and narrow. After unstrapping the container, he backed right into the dug-out channel and lifted the dump bed, sliding the steel hulk onto the gravel base. Then he slowly eased the truck out from under the container. Pretty as you please, it was right where we wanted it.

Containerize

Now we had to prepare the unit for burial. Bob-O bought a 5-gallon bucket of roofing sealant and a couple of cheap paint rollers for one-time use. I had him buy us each disposable paper overalls. That weekend, we tackled the job of coating the entire outside of the container with the sticky, tarry stuff.

The coating went on easily, but it stuck to everything and everyone. Where the black stuff smeared on our protective overalls, it seeped right through. There was no way to keep our hands from being completely covered. We got the sides done and put the brushes and pans into a plastic garbage bag to keep them moist. We needed to let the sides dry before we painted the top.

We were ready to shuck our overalls and clean the muck off our hands when Bob-O made the realization: There were no cleanup instructions on the 5-gallon bucket. We tried alcohol, hydrogen peroxide, pumice soap—nothing worked.

Then I remembered something that happened in high school: an oil tanker spill in the San Francisco Bay. My science club went on a field trip to help clean oil off the beaches. That was some nasty stuff, and the only way we could get the crude oil off was to emulsify it with baby oil first. Bob-O and I tried it. Bingo!

Shoring Up

We then decided to dig our channel a little more back into the hill. There was seven feet from the back of the container to the dirt end of the channel. Bob-O used the backhoe bucket and scooped out four more feet. By doing this, we were able to have earthen sides on the entire length of the box to help stabilize inside temperatures.

Ocean-going containers have incredibly sturdy steel columns at each corner—that's how they can be stacked up eight-high. The top corners have cutouts to run rigging through so the container can be lifted into position on a freighter or a railway car, or onto a dock. We chained up the container and pulled it back into the channel, leaving less than 1 foot of clearance to the dirt cutout.

The sides and the top also are steel, but thinner. Bob-O had to reinforce the ceiling using wooden beams. He did as the delivery driver suggested and forced the top into a slight convex curve along the length of the box, so the water would not pool on the roof, but would drain to the sides. Then we rubber-sealed the roof so that everything but the bottom and the doors on the end were waterproofed.

Years ago, our hay barn fell down and we saved the corrugated roof tin in our "boneyard." Bob-O set pieces of the tin upright against the back and walls of the container and backfilled dirt against the tin. This gave us some leeway in the expansion and contraction of the dirt and an extra layer of metal next to the walls. When wet ground freezes, as it does here every year, it expands slowly, inexorably. Picture cream pushing up the cap of a freezing milk bottle. The extra layer of tin reinforced the thin walls of the box and would give and take under pressure from the dirt. The corrugations would facilitate drainage to the gravel below. We also laid barn tin over the roof before piling a foot or so of dirt on top. This we seeded with a soil-stabilizing mix of grass.

Harvest Port

I wish I were as well-traveled as our container. The stickers on the doors pointed to the many foreign ports it has seen. Now our mission was to keep the temperature in the box as low as possible. This meant the large, metal, dark-blue doors had to be painted a heat-reflective color, and white works best. I took photos of all the stickers, then painted the doors white. Where they had been hot to the touch in the sun before, now they were merely warm.

At the local Habitat for Humanity ReStore, we bought a prehung, solid-core exterior door. Bob-O framed a wall 2 feet back into the box and installed the door into the wall—creating a room inside the box. We insulated the wall using 6-inch-thick fiberglass batts and then sheathed it with plywood. Cans of spray insulation foam took care of any awkward edges. Now we had insulated between the exterior doors and the storage area.

We installed a battery-powered, digital high/low temperature sensor into the box. It also measures humidity, but does not record it. We needed to keep track of the temperature fluctuations. Then we would know what we could store successfully.

We bought and assembled shelving for the storage area. I began moving goods out to the shelves. Until we get a good idea of the temperatures in the box, only non-food items will be stored there. Canned food storage should be between 50°F and 70°F, whereas wine should be stored at 50°F to 60°F. What else we will store there depends on where the temperature range falls.

We've been told it will take about a year, and certainly through a complete winter, for the now-aerated soil to compact itself around the container. Although still 80% empty, the container storage is already relieving the crowding in our basement. Now we can contain our hard-won harvest of organic food and maybe even our wine—without using any energy at all.

Zombie-Proof Storage

My niece Tesla and her friend Maureen have assured me that with all our nifty off-grid improvements, we will be surviving the upcoming Zombie Apocalypse (their idea of Armageddon). Maureen is skilled in livestock care, and both can spin, knit, and crochet wool—skills we would need for the long haul.

I'm totally taking them up on their offer of joining us. When the zombies come, we'll be ready, and even if they don't, my hard-won harvest will be safe.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is pickling, canning, drying, fermenting, and freezing the harvest at her off-grid home in northernmost California.


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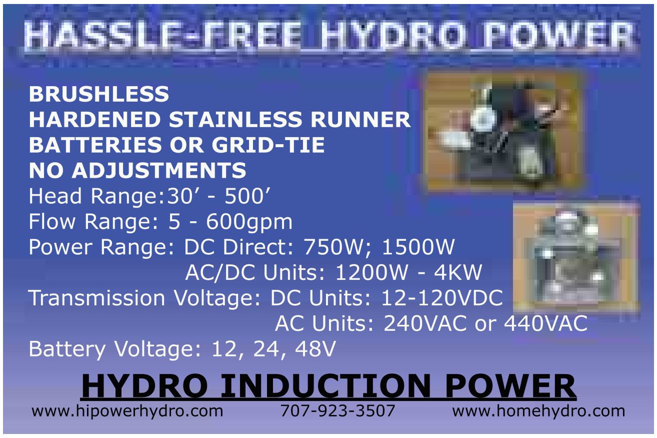
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Climate Factors & Home Heating

Degree days are used for home design, insulation value requirements in codebooks, and for anyone who wants to quantify how cold or hot it is. If you want to heat your home with solar energy, you'll need to know the heating degree days (HDDs) to accurately predict how much of your home's heat load the sun will provide. How many days require you to put a log on the fire or turn on the air conditioner to be comfortable?

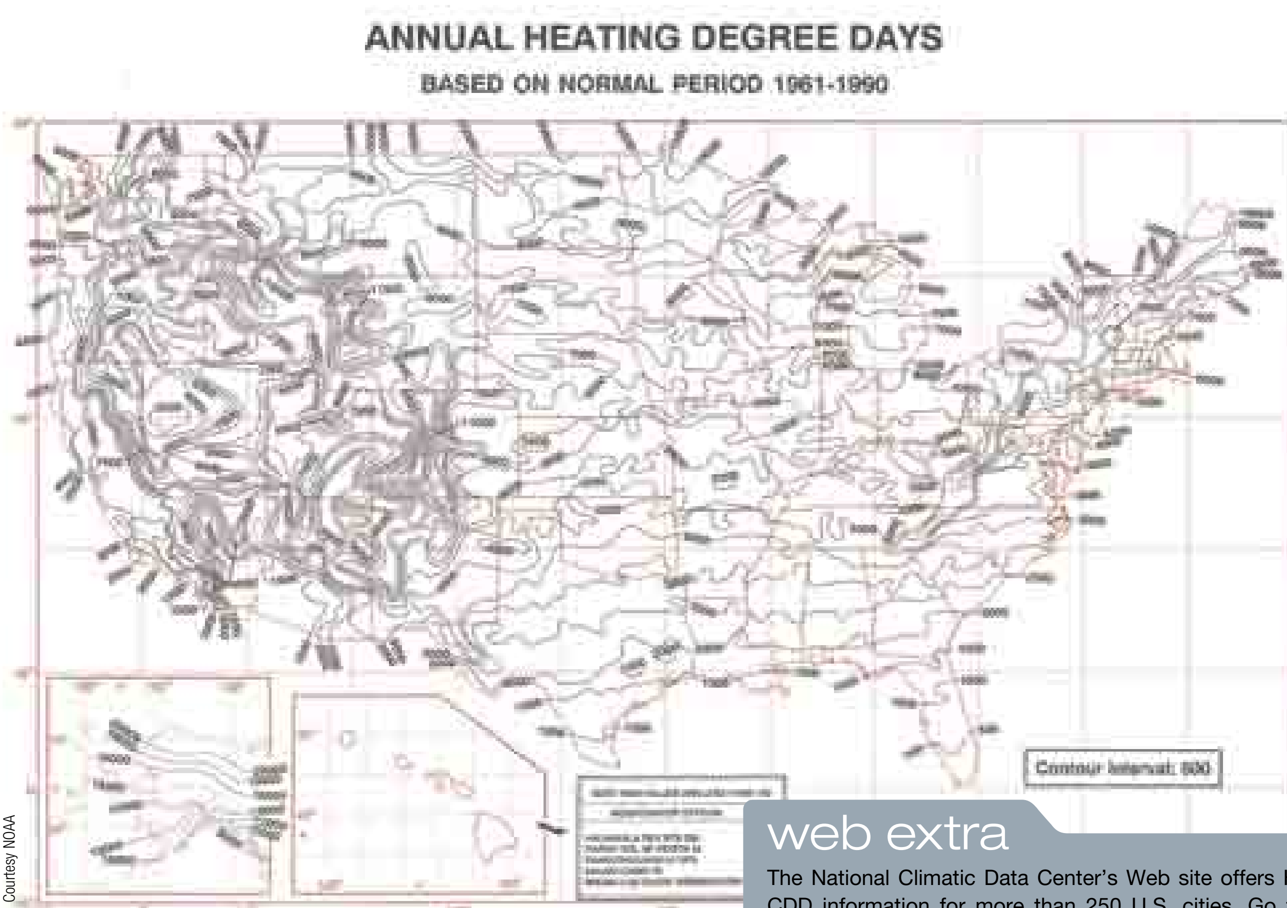
An HDD is the difference between 65°F and the average daily outside temperature. For example, if the average temperature for a given 24-hour period is 25°F, that day would be recorded as having 40 HDDs (65°F – 25°F = 40), indicating that supplemental heat might be needed to maintain a comfortable indoor temperature.

Winter "design temperature," which is dependent on the average annual record low for a location, is used to size a heating system. Temperatures lower than the design temperature will, on average, only be experienced 1% of the time, so it's also known as 99% design temperature.

Relative humidity and infiltration heat losses (or gains) due to wind affect human comfort, and this data isn't reflected in degree-day information. Besides climate, a home's construction also influences its heat loss—i.e., how much insulation is in the envelope, how airtight it is, how many windows are present.

Heat loss is typically expressed in Btu per hour per square foot per degree Fahrenheit, and is a complex calculation best done by an HVAC designer or engineer. Degree-day information and record minimum temperatures give designers the needed information to calculate heat loss. The HDD information is used to estimate the annual cost of heating the home or building. Design temperature is used to ensure that a suitable appliance will have an output greater than the home's calculated heat loss. Thermal comfort varies with each individual and home, but homes that are well-insulated and energy-tight are more resistant to degree-day changes.

—Chuck Marken



Courtesy NOAA

web extra

The National Climatic Data Center's Web site offers HDD and CDD information for more than 250 U.S. cities. Go to **www.ncdc.noaa.gov/oa/ncdc.html**, then click on "Free Data," and select "Comparative Climatic Data" to find information for a city near you.